International Journal of Plant & Soil Science

Volume 35, Issue 20, Page 24-33, 2023; Article no.IJPSS.106037
ISSN: 2320-7035

Efficacy of Neem and Eucalyptus Leaf Powders for the Management of Maize Weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in Dried Sweet Potatoes

David Ojuu [a,b*], Daniel Jude Agolei [a], Robert Amayo [a], Charles Andiku [a], Deborah Alibo [a] and Geoffrey Turyasingura [a]

[a] Department of Crop Production and Management, Faculty of Agriculture and Animal Sciences (FAAS), Busitema University, Arapai Campus, P. O. Box-236, Tororo, Uganda.
[b] Ateker Transformation and Sustainability Initiatives (ATSI), Soroti, P. O. Box-781, Soroti, Uganda.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i203782

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/106037

Original Research Article

Received: 07/07/2023
Accepted: 10/09/2023
Published: 16/09/2023

ABSTRACT

Maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) is a polyphagous storage pest in many crops of economic and food security importance. Its management currently relies mainly on synthetic chemical pesticides. However, plant botanicals are known to exhibit insecticidal properties which can be used to manage the weevil in stored dry sweet potatoes. To study the effect of neem and eucalyptus leaf powders, an experiment was set up at Busitema

*Corresponding author: E-mail: davidojuu@gmail.com;

University laboratory. Neem and eucalyptus leaves were processed into powders. 400g of dried sweet potato chips were weighed and placed in 4 different plastic buckets. Under laboratory conditions, buckets were inoculated with 30 unsexed newly emerged adult weevils. To each bucket, 40g of leaf powders were introduced as single powders and a combination. The experiment was replicated three times. Data on mortality, growth inhibition, produce damage and weight loss was collected over a period of 84 days. Analysis of variance showed that all plant powders showed significant (*P*<0.001) increase in mortality and inhibition of maize weevil and a decrease in damage and weight loss of sweet potato compared to control. The combination showed superiority in all parameters measured. Effectiveness of the plant powders was in the order; combination (neem + eucalyptus) > neem leaf powder > eucalyptus leaf powder.

Keywords: Efficacy; neem; Eucalyptus; leaf powders; Sitophilus zemais; sweet potatoes.

1. INTRODUCTION

Sweet potatoes (*Ipomea batatas*) is an important crop that covers 55% of arable land in Uganda (Tinyro & Mayanja, 2018; [1]. The crop is ranked third to cassava and plantains in terms of food security. In Teso-sub region, ranks second after cassava as a food security crop [2]. The crop is considered drought tolerant, hardy and can grow in marginal areas, it has is produced in two growing seasons [3] thus contributing to improved food security [4] for farming communities in semi-arid conditions and marginal soils. Based on production characteristics of sweet potatoes, it hence possess immense potential to contribute to addressing Sustainable development goals of zero hunger and no poverty [5]. Despite its importance, farmers have continued to incur losses of this high value crop in storage mostly due to storage pests like; larger grain borer, lesser grain borer, and *S. zeamais*. It is observed that farmers make huge losses even in the dried sweet potato chips due to *S. zeamais*, as they become powder wthin 2-3 month of storage [6].

Maize weevil (*Sitophilus zeamais*) a polyphagous chewing pest that has been reported as a serious threat in maize storage including other crops [7]. The maize weevil also infests other types of stored, products such as sweet potatoes, cassava, and various coarse, milled grains causing quantitative and qualitative losses up to 90% under serious infestation [8]. The management of storage pests has relied on synthetic insecticides inform of fumigants [9]. However, the chemical insecticides have limitations such as food safety, human health and environmental hazards associated with their use in stored agricultural produce [10,11]. Due to associated challenges with the use of chemical insecticides in stored foods, research efforts on alternative plant-based products has gained momentum in the recent years [12].

Traditionally, farmers have employed indigenous knowledge like use of whole plant parts and plant ash in control of storage pests. Botanicals plants are historically known to have insecticidal properties [13]. Insecticidal plants such as Neem and Eucalyptus (*E. tereticornis*) are common and easily accessible to a majority of farmers in Uganda (Trivedi et al*.,* 2018), [14]. Being cheap and eco-friendly nature makes them used in as protectants to S*.zeamais* among smallholder farmers [15].

The neem leaf and eucalyptus powders and oils have been used as powders in the control of *S. zeamais* in yams [16], rice [17], and maize [14]. Musundire et al., [18] investigated the efficacy of Eucalyptus grandis and Tagetes minuta ground leaf powders as grain protectants against *S. zeamais* in stored maize and recorded significantly minimum grain damage and infestation on 96 days post treatment. Although the effectiveness of seed oil and leaf extracts have been experimented as single applications, the potency of leaf powders of the two insecticidal plants has not been tested in stored dry sweet potatoes so far. Therefore, the present study on testing the efficacy of neem and eucalyptus as single powders and their mixture in managing *S. zeamais* on dried sweet potato chips as potential cost effective and environmentally friendly management option for *Sitophilus zeamais* in stored dry sweet potato chips in smallholder farmers storage conditions. The present study had the overall objective to assess efficacy of neem and eucalyptus leaf powders on management of storage pest of sweet potatoes as an ecological strategy for healthy food management among smallholder farmers. Specifically, the study sought to determine the effect of neem and eucalyptus leaf powders on infestation of sweet potato chips by Maize weevil and secondly, determine the effect of neem and eucalyptus leaf powders on damage of sweet potato chips by maize weevil under storage conditions.

2. METHODS AND MATERIALS

2.1 Description of Study Location

The experiment was conducted at Busitema University laboratory (1°46' 48.00"N, 33° 37' 30.00"E) in Soroti District, Eastern Uganda. Dried sweet potato chips were used as experimental material for the study. Fresh Sweet potatoes were collected from Arapai market and prepared into dry chips**.** FAO/TECA, [4] procedure was modified by peeling potatoes as is the practice with most farmers. The sweet potato tubers were washed in clean water to remove any soil adhering to the tubers. Using a clean kitchen knife, the skin (covering) of each tuber was peeled off. After peeling of the tubers, the same knife was washed clean and used to slice tubers into light longitudinal chips. The chips were later spread on a clean tarpaulin for sun drying. The drying process was allowed for seven days until all the slices/chips were crispy dry.

2.2 Preparation of Plant Powders

The leaves of eucalyptus and neem test plants were obtained from Busitema University- Arapai campus; 1^0 40’50” N 33^0 45’34” E and elevation of 1060m above sea level. The leaves were washed under running tap water to remove impurities and then dried under shade for 20 days at room temperature until crispy dry to conserve the active ingredients, upon proper drying, the leaves were crushed into powder using an electric grinding machine and then packed. In order to prevent loss of quality, polythene bags were used to store and seal the powders at room temperature [19].

2.3 Rearing of the Experimental Insects

Adult maize weevils used in the experiment were reared in plastic containers under ambient laboratory temperature of 30±3^{o}C and relative humidity of 75±3%. Weevil-infested potatoes chips were sourced from farmer stores within Arapai community and were put in culture vials measuring 12cm wide and 14cm long before they were incubated in the laboratory cupboard so that the old insects will mate and oviposit. This was left undisturbed under laboratory conditions of temperature within 30±3^{o}C and relative humidity of 75±3%. for one and a half months and the newly emerged adults were used for the experiment.

2.4 Treatment of Sweet Potato Chips with Plant Powders and Inoculation of Test Insects

400g of dried sweet potato chips were weighed using a digital scale China model WH-B05 and placed in each of the 4 plastic buckets of dimensions; 30cm wide and 45cm long. A total of 30 unsexed newly emerged weevils 1-10 days old were introduced to each of the buckets containing sweet potato chips. The buckets containing weevils and sweet potato chips were then randomly treated with 40g of neem leaf powder, eucalyptus leaf powder and a combination (neem + eucalyptus) each contributing 20g, the control bucket did not receive any treatment. The experiment was replicated thrice and treatments were randomly assigned using the table of random numbers. The culture was maintained at temperature of 30±3^{o}C and humidity of 75±5% for 84 days as adopted by Muzemu et al*.,* [8].

2.5 Description of Experimental Design and Layout

The experiment was conducted in Completely Randomized Design with four treatments such as neem leaf powder 40g/0.4kg of sweet potato chips, eucalyptus leaf powder 40g/0.4kg of sweet potato chips and a combination of neem and eucalyptus powder 40g/0.4kg of sweet potato chips each powder contributing 20g and untreated control with only 0.4kg of sweet potatoes. Each treatment was replicated four times. Thirty unsexed, 1-10 days old maize weevils were introduced to each bucket containing respective treatments mentioned above, the open ends of the buckets were covered with a muslin cloth to prevent escape of insects and continued for 84 days during which data was collected.

Data viz; mortality of adult weevils (%) and inhibition of growth rate and emergence of new insects rate percent damage of potato chips and weight loss (%) were recorded.

2.6 Adult Mortality

Data on adult mortality was obtained by counting the number of dead adult weevils in the plastic bucket after application of treatment. The data was recorded for a period of 35 at 7 day interval (7, 14, 21, 28 and 35 days) and the percentage mortality was computed using the following formula [20].

$$\text{Percentage mortality (\%)} = \frac{\text{Number of dead maize weevils}}{\text{Number of introduced maize weevils}} \times 100$$

2.7 Newly Emerged Weevils and Inhibition Rate

The number of newly emerged adults was counted starting from the 35th day after oviposition till the 84th day at 7 days interval. The data on emergence of new *S.zeamais* neonates were recorded between the 35th and 56th days. The inhibition rate was calculated from the formula as previously described by Ahad et al., [21].

$$\text{Inhibition Rate (IR)} = \frac{\text{Cn} - \text{Tn}}{\text{Cn}} \times 100\%$$

Where;

C_n= Number of insects in control bucket.
T_n= Number of insects treated bucket.

2.8 Percentage Damage on Sweet Potatoes Chips

Plant powders were tested for potato chips damage on the 84th day of the experiment by randomly selecting 10 sweet potato chips from each container, and chips with bore holes were considered as damaged and their number was recorded in each replication. The percentage damage was calculated using the following formula [22].

Percentage potatoes chips damage (%) = $\frac{G1}{G2} \times 100$

Where, G_1 = Number of potatoes chips with hole, G_2= Total number of the randomly selected dried potatoes chips.

2.9 Percentage Weight Loss

Data on weight loss was taken on the 84th day of the experiment by sieving off all the powder particles from sweet potatoes. The plant powders and leaving behind the sweet potato chips which were weighed separately using a digital scale from each replication and recorded. The initial weight had been noted early on the first day of experiment set up as 400g for all replicates. Weight loss was then obtained from the formula adopted by Loko et al., [20];

$$\text{Percentage weight loss} = \frac{\text{Initial weight of chips} - \text{final weight of chips}}{\text{initial weight of chips}} \text{x}100$$

2.10 Data Analysis

The per cent mortality, damage,weight loss and inhibition rate were subjected to the analysis of variance (ANOVA) procedure using GenStat 12th edition [23] to generate Means, least significant Differences (LSD), Coefficients of Variation (CV) and F-probability. Treatment means were compared using Bonferroni test at 0.05 level of significance [24].

3. RESULTS

The generalised analysis of variances showed that all treatment had significant effect on mortality of the S. zeamais ($P<0.05$), the effect on of treatments on emergence of insects was highly significant ($P<0.001$) over the experiment period, similarly the inhibitory effect of leaf powders on insect growth was observed to highly vary significantly. The damage of S. zeamais on dried sweet potato chips significantly ($P<0.05$) varied among treatments while weight loss was highly significantly ($P<0.001$) varying across treatments. The effects of treatments over time was observed to be highly significant for mortality, number of emerged insects and inhibition of insect growth (Table 1).

3.1 Mortality of *Sitophilus zeamais*

The analysis of variance showed that there was significant variation in mortality ($P<0.001$) in all the treatments during the treatment period and among treatment interaction with time (Table 2). When mortality of weevils was studied at 7,14, 21, 28 and 35 days of exposure to treatments, results showed that there was increase in mortality with time for all treatments, the greatest mean mortality (92.2%) was achieved on the 35th day after treatment however there was no statistical difference in mean mortality between the 28th and 35th day. The treatment interaction showed that the combination (Neem + eucalyptus) increased mortality up to 74.9%, the least mortality was observed in the control 13.8%. There was no significant difference in mortality of *S. zeamais* between neem leaf powder and eucalyptus leaf powder (Table 3).

Table 1. Anova table showing mean sums of square for parameters measured

Source of variations	df	MS	df	MS			
		Mortality (%)		Emerged insects (Numbers)	Inhibition rate (%)	Damages (%)	Weight loss (%)
Treatment	3	10746.2***	3	269.4***	18567.9***	875.0***	564.2***
Time interval (Days)	4	9445.7***	3	386.4***	1786.1***	-	-
Treatment X Time interval	12	495.4***	9	27.1***	370.5***	-	-

*Numbers followed by the stars are the mean sums of squares, Values are mean sums of squares, df= degree of freedom, %=percent, *** means highly significant at P<0.001*

Table 2. Effect of treatments on the mortality of *S. zeamais*

	Mortality (%)					
Treatments	**7 DAT**	**14 DAT**	**21 DAT**	**28 DAT**	**35 DAT**	**Mean**
Control	0.0	8.9	16.7	17.8	25.6	13.8a
Eucalyptus	10.0	35.6	77.8	86.7	87.8	59.6b
Neem	13.3	38.9	81.1	87.8	91.1	62.4b
Neem + Eucalyptus	23.3	57.8	96.7	97.8	98.9	74.9c
Mean	15.6a	44.1b	85.2c	91.1d	92.2d	65.6
Se	1.836					
LSD	5.255***					
CV (%)	6					

*DAT= Days after treatment, LSD=least significant difference, CV=Coefficient of variation, same letters following means down the column and along the rows show no statistical difference and ***highly significant P<0.001*

3.2 Newly Emerged Weevils and Inhibition Rate

The treatments showed highly significant (*P*<0.001) effect on insect emergence; combination of eucalyptus and neem leaf powders showed the lowest emergence of new insects ((2.8 insects), followed by neem leaf powder (4.3 insects), eucalyptus leaf powder (5.3 insects), while the highest number of new insects (13.3 insects) was observed in control. Observations over time showed that on the 35th day, 4 new weevils had emerged in the control whereas no new emergences were registered in neem leaf powder and eucalyptus leaf powder up to the 42nd day after treatment. New insect emergencies were observed in the combination for the first time in the 49th day after treatment. By the 56th day only 7.3 weevils had emerged in the combination, 9.7 in neem leaf powder, and 11.3 in eucalyptus leaf powder compared with 26.0 weevils in the control (Table 3).

It was observed that, all plant powders showed an inhibitory effect on *S. zeamis* growth. Significant differences P<0.001 among powders and the duration of exposure to treatments was recorded. Inhibition was highest in the combination (Neem + Eucalyptus) 87.4% followed by neem leaf powder (75.8%) and eucalyptus leaf powder (67.9%). Complete inhibitory effect recorded while the use of Neem and eucalyptus leaf powders was sustained up to 49 DAT whereas, individual application of insecticidal powders only inhibited the weevil emergence up to 35 days. It was also observed that inhibition rate decreased with increase in days of exposure to botanical powder treatments from 75.0% (on 35th DAT to 47.6% on the 56th DAT (Table 4).

3.3 Percentage Damage on Sweet Potato Chips by *S. zeamais*

Mean percentage damage was observed to be significantly lowest (20%) in combined application of Neem and Eucalyptus powder treatment when compared 60% highest) was observed in control buckets. The use of Neem and Eucalyptus separately showed, low damage at 30% and 40 respectively. Similarly, there was significant variation in weight loss between treatments (p<.001). The lowest weight loss (3.18%) was observed in treatment where Neem and Eucalyptus leaf powders were used in combination followed Neem alone (9.89%) and Eucalyptus (10.24%) while control had the highest weight loss was observed at 34.42%.

Table 3. Effect of plant powders on emergence of *S. zeamais*

Time interval (Days)	35 DAT	42 DAT	49 DAT	56 DAT	Mean
Treatments	No. emerged insects				
Control	4.0	6.7	16.7	26.0	13.3d
Eucalyptus	0.0	3.0	6.7	11.3	5.3c
Neem	0.0	1.7	5.7	9.7	4.3b
Neem + Eucalyptus	0.0	0.0	3.7	7.3	2.8a
Mean	1.0a	2.8b	8.2c	13.6d	6.4
SE	0.491				
LSD	1.418***				
CV (%)	13.3				

*DAT= Days after treatment, S.E-Standard error, LSD- Least Significant difference, CV-Coefficient of variation, *** Significance at P<0.001*

Table 4. Inhibitory effect of plant powders on emergence of *S. zeamais* in dried sweet potato chips up to the 56th day of treatment duration

Time interval (Days)	35 DAT	42 DAT	49 DAT	56 DAT	Mean
Treatments	Inhibition rate				
Control	0.0	0.0	0.0	0.0	0.0a
Eucalyptus	100.0	55.6	60.1	56.1	67.9b
Neem	100.0	74.6	65.9	62.8	75.8c
Neem + Eucalyptus	100.0	100.0	77.9	71.5	87.4d
Mean	75.0c	57.5b	51.0a	47.6a	57.8
SE	2.811				
LSD	8.118***				
CV (%)	8.4				

*LSD- least significant difference, SE- standard error, CV- coefficient of variation, *** Significance at P<0.001*

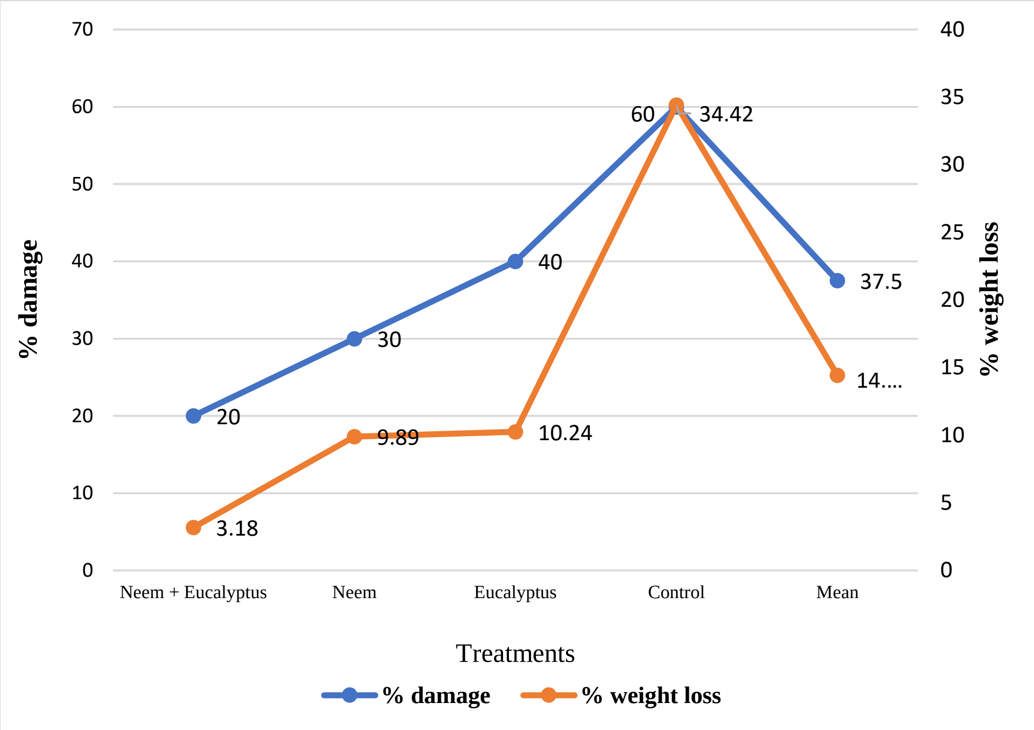

Fig. 1. Variations in damage and weight loss due to *S. zeamais* on dried sweet potato chips under storage

4. DISCUSSION

The experiment was conducted to evaluate the effect of Neem and Eucalyptus leaf powders when used singly and as combination on mortality, emergence, growth inhibition of *S. zeamais* and rate of damage and weight loss of dried sweet potato chips when treated with the two botanical pesticides. Results showed the highest mortality of maize weevil in treatment combination, followed by single applications of neem and eucalyptus leaf powders. The increased mortality in the combination could be due to the additive or synergist effect of the powders in acting as fumigants. The progressive mortality observed in this study is associated with the slow action of active ingredients (azadirachtin and eucalyptol) in the powders and delayed mortality of *S. zeamais* might be due to their slow action [25] (NRC, 1992). It was observed that difference in mortality of maize weevil was not significantly different between 28 DAT and 35 DAT implying the time of exposure of the maize weevil to the insecticidal plants is not significant after 28 days of treatment, similar observations were made in maize [26]. The findings in the current study align with earlier studies of Erenso & Berhe, [14] who tested the effect of neem leaf and seed powder against maize weevil and reported mortality of 61.13, 68.76 and 77.75% within 10, 30 and 45 days respectively. Study conducted by Shiberu and Mulugeta., [27] on the determination of appropriate dozes of botanicals against maize weevil had revealed 100% mortality when applying 5g of neem leaf powder/100g of maize grain. The present findings showed potency of the leaf powders in causing mortality of *S. zeamais* in stored sweet potato chips, however, the efficacy of botanical leaf powders can be influenced by application dosage, size of chips and storage conditions as well as the extent of contact between the insecticide and the pest [28]. This implies optimal the benefit of insecticidal leaf powders for storage pest management involves depends on optimal application rates, storage conditions and state of produce.

All plant powders showed inhibitory effect to *S. zeamis* with a highly significant difference among the powders and powder interaction with time at $P<0.001$. The inhibitory ability of powders was in the order; combination (neem + eucalyptus) > neem leaf powder > eucalyptus leaf powder. The results in this study are attributed greatly to the inhibitory activity of azadirachtin and eucalyptol present in neem and eucalyptus respectively. These active ingredients could have delayed or inhibited oviposition, feeding, growth and development of the insects by blocking the ecdysone hormones which control those vital insect physiological processes thereby reducing the number of neonates compared to the control, the high delay in emergence of neonates in the combination (neem + eucalyptus) could be due to the synergistic effects of the powders [7,27]. Our study confirmed those of Soujanya et al. [15] who reported botanical pesticides inhibit development of immature neonates of storage pests of agricultural produce.

It is observed that all the plant powders significantly reduced damage on dried sweet potato chips due to *Sitophilus zeamais* in comparison to the untreated control, this could be attributed to the toxicity by the insecticidal plant powders by acting as fumigants [8] and inhibitory effects of the powders against *S. zeamais.* The significantly lower damage due to combined application of Neem and Eucalyptus is attributed to synergistic effect of the powders in causing deterrence to the weevils feeding [12]. The results of this current study are in line with findings of Ehisianya [29] who reported 68% damage in the control of maize weevil when *Imperata cylindrica* powder was used in stored maize.

Potato weight loss was recorded in all treatments, however, maximum loss in weight of sweet potato chips due to *S. zeamais* damage was recorded in the untreated control followed by eucalyptus > neem > combination (neem + eucalyptus) and were significantly different $P < 0.001$ for all treatments. The reduced weight loss realized with the powder treated sweet potato chips is as a result of reduced damage which could be due to feeding deterrence of the adults and larvae of the weevils. Similar findings were reported by Musundire et al., [18] on maize weevils under storage conditions. The low damage observed in the treated sweet potato chips could be attributed to the dehydration effect of botanical powders as well as reduced humidity in storage buckets that affected weevil survival, egg deposition and activity [26]. This point to the potential of botanical pesticides in influencing ecosystems services provisioning for effective storage of agricultural produce.

5. CONCLUSION

The plant leaf powders in the current study have shown effectiveness as management options for *S.zeamais* in stored sweet potato chips when applied as combination or as individual botanical pesticides. The combined application of Neem and Eucalyptus leaf powders show increased efficacy in management of the storage pest as compared to singular applications. The effectiveness of the plant powders was in the order; combination (neem + eucalyptus) > neem leaf powder > eucalyptus leaf powder. Generally, the botanical pesticides showed increased mortality of the weevil, slow population build-up in the experimental buckets and reduced damage and weight loss on sweet potato chips. Implying best results from the two botanical plants are realised when they are applied together rather than as sole application. The results also show that the inhibitory effect of plant leaf powders decreases with time of application, similarly, weight loss associated with damage by the weevil tends to increase with time of application of the leaf powders, therefore reapplication of leaf powders can be better strategy to enhance long term effect of the leaf powders in management of storage pests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author [DO] upon reasonable request.

ACKNOWLEDGEMENTS

The output of this research was supported by Ateker Transformation and Sustainability Initiatives with funding from the McKnight Foundation on implementation of Farmer Research Network Approach. The opinions expressed herein are those of the author(s) and do not reflect those of the project management.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Abong GO, Ndanyi VCM, Kaaya A, Shibairo S, Okoth MW, Lamuka PO, Odongo NO, Wanjekeche E, Mulindwa J, Sopade P. A review of production, post-harvest handling and marketing of sweetpotatoes in Kenya and Uganda.

Curr Res Nutrition Fd Sci. 2016;4(3): 162–181.
Available:https://doi.org/10.12944/CRNFSJ.4.3.03

2. Epeju WF, Rukundo PM. Food security and income through sweet potato production in Teso, Uganda. Sustainable Agric Res. 2017;7(1):146.
Available:https://doi.org/10.5539/sar.v7n1p146
3. Namanda S, Gibson R, Sindi K. Sweetpotato seed systems in Uganda, Tanzania, and Rwanda. J Sust Agric. 2011;35(8):870–884.
Available:https://doi.org/10.1080/10440046.2011.590572
4. FAO- Food and agriculture organization of the United Nations FAO TECA. Making sweet potato chips and flour; 2020.
Available:https://www.fao.org/teca/en/technologies/6904.
5. UN [United Nations]. The Sustainable Development Goals Report 2019. United Nations Publication Issued by the Department of Economic and Social Affairs. 2022;64.
Available:https://unstats.un.org/sdgs/report/2022/%0Ahttps://www.un-ilibrary.org/content/books/9789210018098%0Ahttps://www.un-ilibrary.org/content/books/9789210478878
6. Agona JA, Nahdy DP, Giga DP, Rees D. A visual scale of loss assessment for dried sweet potato chips due to *Araecerus fasciculatus* Degeer (Coleoptera: *Anthribidae*) infestation on-farm. Uganda J Agric Sci.1999;4(1):1–5.
7. Barre J, Jenber AJ. Evaluation of selected botanicals for the management of maize weevil (*Sitophilus zeamais*) on maize (*Zea mays* L.) grain under laboratory condition in Gabilay District, Somaliland. Heliyon. 2012;8(12): e11859.
Available:https://doi.org/10.1016/j.heliyon.2022.e11859
8. Muzemu Simbarashe, Chitamba JMB. Evaluation of *Eucalyptus tereticornis, Tagetes minuta* and *Carica papaya* as stored maize grain protectants against *Sitophilus zeamais* (Motsch.) (Coleoptera: *Curculionidae*). Agric ForFisheries. 2013;2(5):196.
Available:https://doi.org/10.11648/j.aff.20130205.13
9. Ojo JA, Omoloye AA. Development and life history of *Sitophilus zeamais* (Coleoptera: *Curculionidae*) on Cereal Crops. Adv Agric; 2016.
Available:https://doi.org/10.1155/2016/7836379
10. Ileke KD, Idoko JE, Ojo DO, Adesina BC. Evaluation of botanical powders and extracts from Nigerian plants as protectants of maize grains against maize weevil, *Sitophilus zeamais* (Motschulsky) [Coleoptera: *Curculionidae*]. Biocatalysis Agric Biotechnol. 2020;27:101702.
Available:https://doi.org/10.1016/j.bcab.2020.101702
11. Mandudzi E, Edziwa X. Eucalyptus leaf powder is effective in maize weevil control. 2016;2:93–98.
Available:https://doi.org/10.5923/j.ijaf.20160602.06
12. Akinneye JO, Ogungbite OC. Insecticidal activities of some medicinal plants against *Sitophilus zeamais* (Motschulsky) (Coleoptera: *Curculionidae*) on stored maize. Arch Phytopathol Plant Prot. 2013;46(10):1206–1213.
Available:https://doi.org/10.1080/03235408.2013.763614
13. Belmain SR, Tembo Y, Mkindi AG, Arnold SEJ, Stevenson PC. Elements of agroecological pest and disease management. Elementa.2022;10(1):1–14.
Available:https://doi.org/10.1525/elementa.2021.00099
14. Erenso TF, Berhe DH. Effect of Neem leaf and seed powders against adult maize weevil (*Sitophilus zeamais*Motschulsky) mortality. Int J Agric Res.2016;11(2):90–94.
Available:https://doi.org/10.3923/ijar.2016.90.94
15. Soujanya PL, Sekhar JC, Kumar P, Sunil N, Prasad CV, Mallavadhani UV. Potentiality of botanical agents for the management of post harvest insects of maize: A review. J Fd Sci Technol. 2016;53(5):2169–2184.
Available:https://doi.org/10.1007/s13197-015-2161-0
16. Koradaa RR, Naskara SK, Edison S. Insect pests and their management in yam production and storage: A world review.Int JPest Mgmt. 2010;56(4):337–349.
Available:https://doi.org/10.1080/09670874.2010.500406
17. Devi MB, Devi NV, Singh SN. Effects of six botanical plant powder extracts on the control of rice weevil , *Sitophilus oryzae* L . in stored rice grains. IntJ Agric Innovations Res. 2014;2(5):683–686.

18. Musundire R, Mazodze F, Macheka L, Ngadze RT, Mubaiwa J, Manditsera F. *Eucalyptus grandis* and *Tagetes minuta* leaf powders effectively protect stored maize against *Sitophilus zeamais* without affecting grain organoleptic properties. AfrJ Agric Res. 2015;10(2):49–57. Available:https://doi.org/10.5897/ajar2014.8711
19. Chayengia B, Patgiri P, Rahman Z, Sarma S.Efficacy of different plant products against *Sitophilus oryzae* (Linn.) (coleoptera: *Curculionidae*) infestation on stored rice. J Biopestic. 2010;3(3):604–609.
20. Loko YLE, Gnaho AC, Toffa J, Orobiyi A, Dansi A, Tamo M. Management of *Dinoderus porcellus* L. (Coleoptera: *Bostrichidae*) infesting yam chips using varietal resistance and botanical powders of three medicinal plants. Afr J Agric Res. 2018;13(40):2118–2133. Available:https://doi.org/10.5897/ajar2018.13418
21. Ahad A, Hossain Bhuyain MM, Hoque M, Hoque F. Eco-friendly Management of Lesser Grain Borer, *Rhizopertha dominica* f. (bostrichidae: *coleoptera*) on Wheat in Storage. Am J Life SciRes.2016;4(4):145–151. Available:https://doi.org/10.21859/ajlsr-040407
22. Adedire CO, Lajide L. Toxicity and oviposition deterrency of some plant extracts on cowpea storage bruchid. *Callosobruchus maculatus* Fabricius.J PlantDisease Prot. 1999;106(6):647–653.
23. Payne RE, Harding SA, Murray DA, Soutar DM, Baird DB, Glaser AI, Channing IC, Welham SJ, Gilmour AR, Thompson R, Webster R. The guide to Genstat release 14, part 2: Statistics. VSN International, Hemel Hempstead, UK.
24. Hadebe ST, Modi AT, Mabhaudhi T. Assessing suitability of sorghum to alleviate sub-saharan nutritional deficiencies through the nutritional water productivity index in semi-arid regions. Foods. 2021;10(2). Available:https://doi.org/10.3390/foods10020385
25. Muhammad A. Kashere MA. Neem, *azadirachta indica* l. (a. juss): An eco-friendly botanical insecticide for managing farmers insects pest problems - A review. 2020;6(1):484–491.
26. Mbewe M. Effectiveness of botanical control of *Sitophilus zeamais* (maize weevils) in stored maize grain (*Tephrosia candida, Lantana camara* and *Eucalyptus tereticornis*). Int J Multi-Disiplinary Res. 2016;1–16.
27. Shiberu T. Determination of the appropriate doses of promising botanical powders against Maize weevil, *Sitophilus zeamais* Mots (Coleoptera: *Curculionidae*) on maize grain. Agric ResTechnol Open Access J. 2017;6(5):49–53. Available:https://doi.org/10.19080/artoaj.2017.06.555698
28. Mbah OI, Okoronkwo MO. An assessment of two plant products efficacy for the control of the maize weevil (*Sitophilus zeamais* Motschulsky) in stored maize. 2008;494–498.
29. Ehisianya CN, Ikpi PO, Okore OO. Obeagu IA. Assessment of plant powders as protectants of stored maize grains. 2019;50(1):37–45.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/106037