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Feeding Preference of *Rhyzopertha dominica* Fabricius, 1792 on Four White Yam (*Discorea rotundata* Poir) Chips and Its Control with *Zingiber officinale* Roscoe and *Capsicum annum* L.

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ABSTRACT

Efficacy of two botanicals powders, *Zingiber officinale* and *Capsicum annuum* at different concentrations were investigated as protectants against *Ryzopertha dominica* on four varieties of white yam. Feeding preference of *R. dominica* on yam chips was investigated using choice test. Proximate compositions of the yam varieties were also determined. The experiments were conducted at ambient conditions at the Entomology Laboratory, Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria. Powders from dried products of the two botanicals were applied at three concentrations [0.5, 2.5, 5.0% (w/w)] on four white yam varieties (Gambari, Danacha, Makakusa, Ame) exposed to *R. dominica*. The powders had contact and fumigant toxic effects on the beetles. Mortality increased in with increased concentration and exposure time on Ame variety treated with *Zingiber officinale and Capsicum annuum* at 24, 48 and 72 Hours After Infestation (HAI). The highest mortality (27%) was observed on yam chips treated with *Z. officinale* (5.0 w/w) at 24 HAI. The lowest mortality (17.5%) was observed on 0.5% w/w concentration. At 48 HAI, the highest insect mortality (30.0%) and lowest mortality (25.0%) were observed on infested yams at 5.0% w/w and 0.5% w/w, respectively. At 72 HAI, the highest mortality (37.5%) and lowest insect mortality (32.5%) was observed on yam chips treated 0.5 w/w and 0.5% w/w, respectively. However, for yam chips varieties treated with powder of *C. annuum*, the highest mortality at 24 HAI when at 5.0% w/w was 12.5%. There was no insect mortality when treated at 0.5w/w. At 48 HAI, the highest insect mortality at 24 HAI was 22.5% with treatment application of 5.0 w/w with lowest (5.0%) at 0.5% w/w while at 72 HAI. The highest mortality (30.0%) was obtained at 5.0 w/w, while the lowest adult mortality was 5.0% with 0.5% w/w application. Danacha was the most preferred for feeding and had the highest weight loss (6.75%). The high ash content in Danacha (1.4%) could be responsible for more beetle damage recorded on the chips. These findings indicate that powders of the two botanicals could be used to protect stored yam chips from beetle infestation and damage.

Keywords: *Dioscorea rotundata*, Food preference, Yam chips varieties, *Rhyzopertha dominica*,

INTRODUCTION

Yams are a staple crop in many parts of Africa and Southeast Asia. The crop is second to cassava as the most important tropical root crop; they are essentially carbohydrate foods with relatively high

protein and ascorbic acid (Vitamin C) content compared to cassava or sweet potato. On a world scale, yams represent less than 10% of all root and tuber crops produced and, of these, 75% are grown in West Africa. Yams are cultivated on over 5 million hectares in 47 countries in tropical and subtropical regions of the world. The majority of yams produced worldwide, approximately 94 – 98%, come from the West African yam belt which spans from Cote-d'Ivoire to Nigeria according to FAOSTAT (2021). Originally grown for food security, yam production has transformed into a cash crop that allows smallholder farmers to earn income.

Under tropical conditions, sound tubers will store for up to about four months depending on variety and species, and thus extending the shelf-life through drying or other processes has not had such a high priority with yam as with cassava or sweet potato. However, injured tubers are often peeled, sliced and sun-dried soon after harvest to extend their useful life. The dried slices are generally milled into flour (often brown/purple in colour due to oxidation of phenolics during drying), which is reconstituted with boiling water to produce "Amala" (in Nigeria) (Ayodele *et al.,* 2013).

The cultivation of yam has been severely constrained by reduction in soil fertility, increase in insect pest infestations and an increase in production cost. Increased pressure from a range of insect pests (leaf and tuber beetles, mealy bugs, scales), fungi (anthracnose, leaf spot, leaf blight, tuber rots) and viruses, as well as nematodes, contribute to sub-optimal yields and the deterioration of tuber quality in storage (Manyong and Oyewole, 1997). In addition to these problems, dried yam chips have been reported to contain mycotoxins (Dasan *et al.,* 2016; Ogara *et al.,* 2017).

The lesser grain borer, *Rhyzopertha dominica,* (Fabricius, 1792) is a pest of particular significance in the United States, Southern Canada, Argentina, India, New South Wales and Southeast Australia. The insect is a field-to-store pest and which may cause economic damage in the store (Adedire, 2001). *Rhyzopertha dominica* is a major pest of stored produce worldwide and has been known to attack a wide variety of commodities. The adults and larvae of the insect bore into undamaged kernels of grain, reducing them to hollow husks. They also survive and develop in the accumulated "flour" produced as the seeds are chewed up.

Presently, insect pests control in stored food products relies on the use of synthetic insecticides, which have some hazards such as pollution of the environment, toxic residues on stored grains, development of resistance by target species, pest resurgence and lethal effects on non-target organisms in addition to direct toxicity to users and health hazard (Ileke and Oni, 2011; Ileke and Bulus, 2012). Thus, there is a need to increase the use of natural and safer protectants for the control of *R. dominica*. The objectives of this study therefore were to investigate toxicities of *Zingiber officinale* and *Capsicum annuum* powders on four yam varieties against *R. dominica* as well as to identify the yam chips that were most appealing to the lesser grain borer in laboratory-based choice tests.

Materials and Methods

All experiments were conducted in the Entomological Research Laboratory, Department of Crop Protection and Environmental Biology (CPEB), University of Ibadan, Nigeria.

Insect Culture

Rhyzopertha dominica were collected from infested cassava chips obtained from Nigerian Stored Products Research Institute

(NSPRI), Ibadan Office and brought to the Entomology Laboratory of Crop Protection and Environmental Biology. The maize grains was sourced from Bodija market and sorted to remove damaged ones. They were thereafter kept in the deep freezer for 7 days to kill any hidden insect and later air-dried in the laboratory to prevent mouldiness (Adedire and Lajide 1999). To raise culture of *Rhyzopertha dominica*, several adults of unknown age and sex were introduced into maize grains in a glass bottle to lay eggs. The adults were removed on the 7th day and the grains were observed for emergence of adult insects used for the study.

Preparation of the Yam Chips

Tubers of four white yam varieties namely, Gambari, Danacha, Makakusa, and Ame obtained from International Institute for Tropical Agriculture (IITA), Ibadan, were peeled, sliced and blanched at 54 °C. The blanched yam chips were left to stand for 24 hours before the water was drained. The yam chips were sun-dried for 7 days and kept in an oven at a temperature of 45 °C for 5 days to kill any foreign infestation on them after drying and to ensure they were dried to constant weight.

Preparation of the Botanicals

Dried ginger rhizome and chilli pepper products were obtained from Bodija Market, Ibadan, Nigeria. The two botanicals were separately ground, and the ginger rhizome powder was sieved through a 3 mm mesh to get a fine powder.

Toxicity of different concentrations of *Zingiber officinale* and *Capsicum annuum* powders against *Rhyzopertha dominica* on four yam varieties

Twenty gram of yam chips of each variety were weighed into a plastic container (11 cm in diameter and 4.5 cm in height). 0.0 g (control), 0.1 g, 0.5 g, 1.0 g corresponding to 0%, 0.5%, 2.5%, 5.0% plant powders were added separately onto the yam chips (Ileke and Bulus, 2012). Ten unsexed newly emerged adults of *R. dominica* were introduced into each of the containers and covered with the lid. Mortality data were collected at 24, 48 and 72 hours after infestation (HAI).

Preparation of the choice chamber.

The experimental units consisted of an improvised choice chamber. The choice chamber comprises four plastic bowls of equal diameter. A cardboard paper was cut into a circular shape. A circle was drawn at the centre of each cardboard. The ring between the two circles was divided into four equal parts. Each cardboard was placed in each plastic bowl and glued to the floor to prevent insects from escaping underneath the cardboard at the base of the bowls.

Determination of the preferred yam chips of *R. dominica*

Twenty-gram (20 g) samples of each of the dried chips were arranged in the choice chamber (CC) in a completely randomized design (CRD). The CC consisted of demarcated cardboard placed in a plastic bowl and covered with muslin cloth; the cardboard was demarcated into 4 equal parts. Forty newly emerged *R. dominica* adults were introduced into the centre circle of each CC. A control experiment was set up where no insect was introduced and used to correct moisture content. Data were collected on the number of adults that migrated after 24, 48 and 72 HAI to each variety and the weight loss of yam chips were calculated at 72 HAI.

The reduction in weight of yam chips was calculated to obtain weight loss caused by the infestation of *R. dominica* at 72 HAI.

The equation below was used in calculating weight loss:

$$\frac{IW - FW}{FW} X\ 100$$

Where:

IW=Initial weight of a sample

FW=Final weight of the sample without frass and insects (Odeyemi and Daramola, 2000)

Experimental design and Statistical analysis

The experimental design used was completely randomized design. Data were analysed using ANOVA, and significant means were separated using the Least Significant Difference.

Results

Mortality of *Rhyzopertha dominica* on four yam varieties treated with *Zingiber officinale* and *Capsicum annuum* powders at different concentrations

The percentage mortality of *R. dominica* on Gambari yam chips treated with different concentrations of *Z. officinale* and *C. annuum* at 24, 48, and 72 Hours After Infestation (HAI) is presented in Table 1.

The highest mortality (20.0%) at 24 HAI was observed on yam chips treated with Z. officinale (5.0% w/w) and was significantly different ($p = 0.05$) from all the other concentrations at 24 HAI, while the lowest mortality (15.0%) was observed on yam chips treated with 2.5% w/w concentration. At 48 HAI, the highest mortality of 35.0% was observed at 5.0% w/w; it was significantly different from mortalities of the insects on yams treated with other concentrations, while at 72 HAI the highest mortality (37.5%) was observed on yams treated with 5.0% w/w treatment concentration. However, for *C. annuum* at 24 HAI, there was no difference in percentage mortality across all concentrations. At 48 HAI, the highest mortality of 7.5% was observed on 5.0 w/w with the lowest mortality (5.0%) on 0.5w/w. At 72 HAI, the most increased mortality (17.5%) was observed on 5.0 w/w and was significantly higher than mortalities from other concentrations, while the lowest mortality of 7.5% was observed on 0.5 w/w.

In Ame yam chips the highest mortality (27.5%) was observed on yam chips treated with *Z. officinale* (5.0 w/w) at 24 HAI while the lowest mortality (17.5%) was observed on 0.5 w/w concentrations (Table 2). At 48 HAI the highest mortality (30.0%) was observed in chips treated with 5.0 w/w of *Z. officinale* while the lowest mortality (25.0%) was recorded at 0.5% w/w concentration. At 72 HAI the highest mortality (37.5%) was observed on 5.0% w/w concentration while the lowest mortality (32.5%) was observed on 0.5% w/w concentration. However, in Ame chips treated with *C. annuum* at 24 HAI, the highest mortality (12.5%) was observed at 5.0% w/w concentration and was significantly different from all other concentrations. At 48 HAI, the highest mortality (22.5%) was observed in yam chips treated with 5.0% w/w. It was significantly different from all other concentrations. At 72 HAI, the highest mortality (30.0%) was observed on chips treated with 5.0% w/w, significantly different from all other concentrations.

The percentage mortality of *R. dominica* on Makakusa yam chips treated with different concentrations of *Z. officinale* and *C. annuum* at 24, 48 and 72 HAI presented in Table 3. At 24 HAI, the highest mortality (27.5%) was observed on yam chips treated with 5.0 w/w *Z. officinale*. At 48 HAI the highest mortality was observed on 5.0 w/w and was significantly different from mortalities recorded on other concentrations. The lowest mortality was observed on yam chips treated with 2.5w/w. At 72 HAI, the highest mortality (45.0%) was observed on 5.0 w/w and was significantly different from the mortalities recorded on other

concentrations. However, yam chips treated with *C. annuum* at 5.0w/w concentration recorded the highest mortality (2.5%) at 24 HAI. At 48 HAI the highest mortality (15.0%) was also observed at 0.5 w/w concentration and it was significantly different from other concentrations. At 72 HAI, the highest mortality (20.0%) was observed on 0.5 w/w, it was significantly different from other concentrations and the lowest mortality (12.5%) was observed on 5.0 w/w (Table 3).

The percentage mortality of *R. dominica* on Danacha yam chips treated with different concentrations of *Z. officinale* and *C. annuum* at 24, 48, and 72 HAI is presented in Table 4. The highest mortality (15.0%) was observed on yam chips treated with 2.5 w/w *Z. officinale*, it was significantly different from other concentrations at 24 HAI, while the lowest mortality (5.0%) was observed on 5.0 w/w concentration. At 48 HAI, the highest mortality (25.0%) was observed on 2.5 w/w, and it was significantly different from mortalities recorded on other concentrations, while the lowest mortality (15.0%) was observed on 0.5 w/w. At 72 HAI, the highest mortality (32.5%) was observed at 2.5 w/w concentration and significantly differed from the mortalities at other concentrations. However, for *C. annuum* at 24 HAI, the highest mortality (7.5%) was observed on 0.5 w/w. At 48 HAI, the most increased mortality (20.0%) was observed on 2.5 w/w; it was significantly different from mortalities observed on other concentrations, while the lowest mortality (10.0%) was observed on 5.0 w/w. At 72 HAI, the highest mortality (22.5%) was observed on 0.5 w/w was significantly different from mortalities recorded on other concentrations. The lowest mortality (15.0%) was observed on yam chips treated with 5.0 w/w concentration.

Lesser grain borer preference for yam chips varieties

The most preferred yam chips varieties for feeding by *R. dominica* were investigated in a choice test at 24, 48, and 72 HAI and results are presented in Table 5. The highest mean number of adults (12.50) was observed on the Danacha yam, while the lowest mean number of adults was observed on the Gambari variety at 24 HAI. At 48 HAI, the highest mean number of adults (13.25) was observed on the Danacha variety, and it was significantly higher than the number of adults observed on Gambari variety (6.0). At 72 HAI, the highest mean number of adults (14.25) was also observed on the Danacha variety, significantly differing from those recorded on the Gambari variety (5.75).

Table 1: Percentage mortalities of *Rhyzopertha dominica* at 24, 48 and 72 hours on Gambari Yam treated with different concentrations of *Z. officinale* and *C. annuum*

Dosage (w/w)	Percentage Mortality					
	Z. officinale			*C. annuum*		
	24 HAI	**48 HAI**	**72 HAI**	**24 HAI**	**48 HAI**	**72 HAI**
0.5	17.5±0.9	22.5±1.0	35.0±1.0	2.5±0.6	5.0±0.6	7.5±0.6
2.5	15.0±0.6	27.5±0.6	27.5±0.6	2.5±0.6	7.5±0.6	15.0±0.8
5.0	20.0±0.7	35.0±0.6	37.5±0.8	2.5±0.6	7.5±0.7	17.5±1.0
Control	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
$LSD_{0.05}$	0.60	0.60	0.60	4.90	4.90	4.90

w/w- weight per weight; LSD- Least Significant Difference

Table 2: Percentage mortalities of *Rhyzopertha dominica* on Ame Yam treated with different concentrations of *Z. officinale* and *C. annuum*

Dosage (w/w)	Percentage Mortality					
	Z. officinale			*C. annuum*		
	24 HAI	**48 HAI**	**72 HAI**	**24 HAI**	**48 HAI**	**72 HAI**
0.5	17.5±0.8	25.0±0.8	32.5±1.0	0.0±0.0	5.0±0.6	10.0±0.7
2.5	22.5±1.0	27.5±1.0	32.5±1.2	2.5±0.6	7.5±0.8	10.0±0.9
5.0	27.5±1.2	30.0±1.3	37.5±1.4	12.5±0.6	22.5±0.9	30.0±1.0
Control	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
$LSD_{0.05}$	10.53	10.53	10.53	5.99	5.99	5.99

w/w- weight per weight; LSD- Least Significant Difference

Table 3: Percentage mortalities of *Rhyzopertha dominica* on Makakusa Yam treated with different concentrations of *Z. officinale* and *C. annuum*

Dosage (w/w)	Percentage Mortality					
	Z. officinale			*C. annuum*		
	24 HAI	**48 HAI**	**72 HAI**	**24 HAI**	**48 HAI**	**72 HAI**
0.5	20.0±0.9	25.0±0.9	37.5±0.9	0.5±0.6	15.0±0.9	20.0±0.7
2.5	5.0±0.6	17.5±0.8	22.5±0.9	2.5±0.6	10.0±0.0	15.0±0.6
5.0	27.5±1.0	35.0±1.3	45.0±1.1	2.5±0.6	10.0±0.7	12.5±0.8
Control	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
$LSD_{0.05}$	9.13	9.13	9.13	4.18	4.18	4.18

w/w- weight per weight; LSD- Least Significant Difference

Table 4: Percentage mortalities of *Rhyzopertha dominica* on Danacha Yam treated with different concentrations of *Z. officinale* and *C. annuum*

Dosage (w/w)	Percentage Mortality					
	Z. officinale			*C. annuum*		
	24 HAI	**48 HAI**	**72 HAI**	**24 HAI**	**48 HAI**	**72 HAI**
0.5	7.5±0.8	15.0±0.9	20.0±0.9	7.5±0.8	17.5±0.8	20.0±0.7
2.5	15.0±0.6	25.0±0.8	32.5±1.0	5.0±0.6	20.0±0.7	22.5±0.8
5.0	5.0±0.6	22.5±1.0	25.0±1.1	5.0±0.8	10.0±1.1	15.0±1.2
Control	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0
$LSD_{0.05}$	7.30	7.30	7.30	8.26	8.26	8.26

w/w- weight per weight.
LSD- Least Significant Difference.

Table 5: Feeding preference of *R. dominica* on yam chips varieties in a choice test

Yam chips variety	Number of Adults		
	24 hours	**48 hours**	**72 hours**
Ame	9.50 ± 2.18	9.75 ± 2.75	9.00 ± 2.35
Makakusa	11.50 ± 0.87	11.00 ± 0.71	11.00 ± 0.41
Danacha	12.50 ± 1.94	13.25 ± 2.25	14.25 ± 2.46
Gambari	6.00 ± 0.91	6.00 ± 1.47	5.75 ± 1.25
$LSD_{0.05}$	4.89	6.02	5.62

Each value is the mean of four replicates.

The percentage weight loss by *R. dominica* at 72 HAI post-exposure on four yam varieties in a choice test is presented in Figure 1. The highest percentage weight loss of 6.75% was observed in Danacha variety, while the lowest was observed in the Ame variety. The weight loss observed in Danacha variety significantly differed from other varieties at $p < 0.05$. Gambari yam chips' weight was reduced by 3.36%, and it was closely followed by Makakusa (3.13%), while the least damaged was Ame which had a weight loss of 1.88% 72 hours after exposure to *R. dominca* infestation (Figure 1).

Proximate analysis of the dried yam samples

The highest moisture content (10.13) was observed on the Danacha variety, while the lowest was on Gambari (Table 6). The highest protein content (4.43) was observed in the Ame variety, while the lowest was in the Gambari variety. The highest ether extracts (0.50) was observed on Ame variety which was significantly different from all other yam varieties. The highest ash content (1.40) was observed on Danacha variety, while the lowest was observed on Ame variety. The highest crude fibre content (1.23) was observed on the Ame variety, while the lowest was observed on the Makakusa variety. The highest carbohydrate content (84.07) was observed in the Gambari variety which was significantly different ($p < 0.05$) from all other varieties (Table 6).

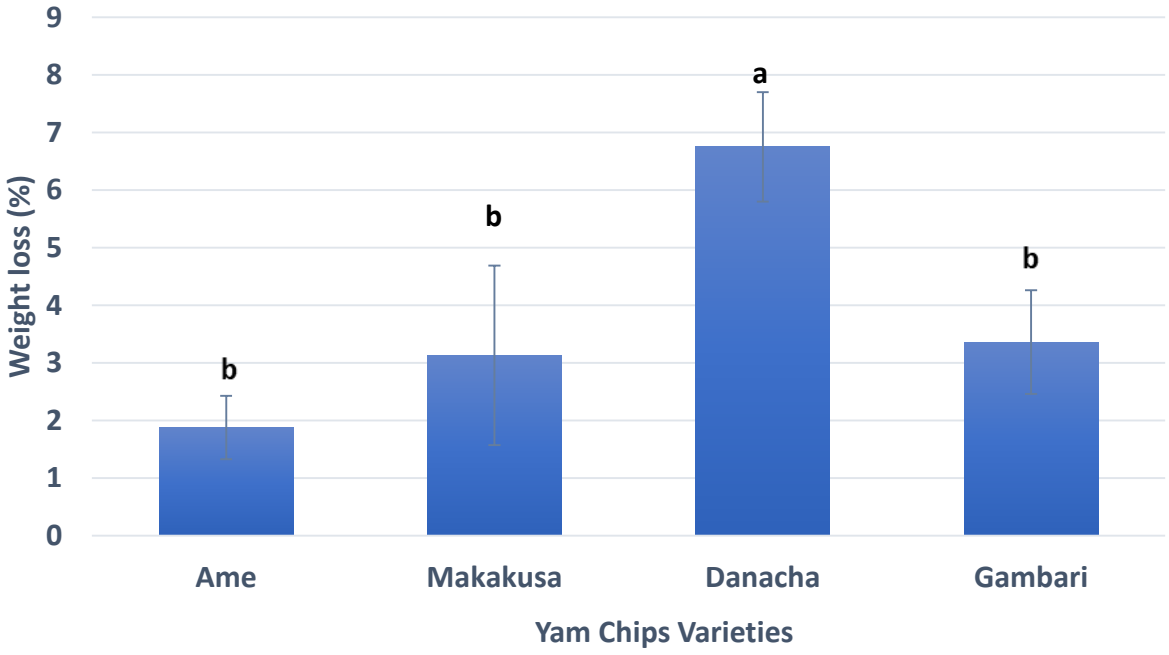

Figure 1: Percentage weight loss by *R. dominica* at 72 Hours on four yam varieties under choice and no choice test

Table 6: Proximate composition of the four white yam chips varieties

Varieties	Moisture Content (%)	Protein (%)	Ether Extract (fats %)	Ash (%)	Crude Fibre (%)	Carbohydrate (%)
Gambari	9.17 ± 0.09	3.97 ±0.03	0.37 ±0.03	1.27 ±0.03	1.17 ±0.03	84.07 ±0.09
Danacha	10.13 ±0.09	4.33 ±0.09	0.33 ±0.03	1.40 ±0.06	1.10 ±0.06	82.70 ±0.06
Ame	10.03 ±0.03	4.43 ±0.09	0.50 ±0.06	1.17 ±0.03	1.23 ±0.03	82.63 ±0.19
Makakusa	9.70 ±0.06	4.10 ±0.06	0.37 ±0.03	1.30 ±0.06	0.93 ±0.03	83.60 ±0.06
$LSD_{0.05}$	0.23	0.23	0.13	0.15	0.13	0.36

DISCUSSION

The results of this study have shown that locally available plant products (ginger and chilli pepper) possess insecticidal properties that can be used to control *Rhyzopertha dominica* on stored yam chips. Ileke and Bulus (2012) reported that the lethal effect of botanicals such as *Azadirachta indica and Piper guineense* seed powders could result from contact toxicity. Similarly, Bandara and Seneviratna (1993) reported that drying ginger rhizomes has been found to reduce its fumigant activity, which may explain why mortality was low (2.5% – 45%) across all the varieties. The significantly high mortalities of *R. dominica* on yam varieties treated with *Z. officinale* may be attributed to the active chemical compounds present in rhizome. It contains pungent compounds such as zingerone, shogaols, and paradol (Ghasemzadeh *et al.*, 2018). Although the active ingredient in *Capsicum annuum* is capsaicin, which gives a burning sensation after ingestion. However, lower percentage mortalities of *R. dominica* were observed on the different yam varieties. The concentrations tested were probably too small to cause significant mortalities in *Rhyzopertha dominica*, which supports the findings of Oni (2010) that significantly low mortality of bruchids was obtained on seeds treated with *C. annuum* and *C. frutescens* fruit powder.

The dose-dependent mortalities observed in this study confirm the study of Ashouri and Shayesteh (2010), who reported that all tested powdered spices possess repellent activity against *Sitophilus granarius, Tribolium castenum* and *Rhyzopertha dominica*, and that the repellency of these powders increased with the increase in dosage as well as increase in the period of exposure to the plant powders.

However, the dose-independent mortalities observed in the other varieties suggest that the varieties' inherent properties were probably incompatible with the botanicals. Ashouri and Shayesteh (2009) reported that plant powders have insecticidal effects on *Sitophilus granarius* and *Rhyzopertha dominica* at all levels of treatment but varied with the exposure period and powder concentration, which certify the results on dose-independent mortalities recorded on Danacha and Makakusa yam varieties**.**

Under the choice test, among the yam varieties tested, *R. dominica* showed a definite preference for Danacha since it had the highest moisture content and this is in line with the findings of Majumder (1975), who reported that soft sweet potato chips played an essential role in determining the susceptibility of a crop to damage by insect pests in store. Also, the high percentage weight loss on Danacha showed that most of the beetles colonised the chips and fed on the tissues, hence the reduction in weight. Aremu *et al.* (2020) opined from their study that the higher moisture content obtained from infested yam (*D. rotundata*) chips

resulted from the presence of insects and their excrement.

Farmers and traders would require to preserve yam chips made from Danacha variety with powders of *Z. officinale* rhizome or *C. annuum* fruit to reduce quantitative and qualitative losses due to beetle infestation. The high moisture would predispose the chips to fungal infections and could lead to food poisoning after several years of bioaccumulation in humans. It is imperative to protect yam chips from beetle infestation during storage. Gambari was the least preferred variety because it had fewer beetles. This suggests that the Gambari variety possesses inherent factors, either biochemical or biophysical, that prevented it from being attacked and damaged by the beetles. Further experiments would be desirable to investigate the underlying basis of its insusceptibility to beetle infestation.

CONCLUSION

This research shows that not all botanicals utilised by farmers in storing their food are very effective. While some are products of chance, others are being used due to their cultural belief or otherwise. The study tested two plant powders, *Zingiber officinale* and *Capsicum annuum*, to verify if they could protect white yam chips from beetle infestation and damage. The powders effectively killed the beetles, with higher concentrations and longer exposure times leading to higher mortality rates. The *Zingiber officinale* powder at 5.0% w/w was the most effective, with a mortality rate of up to 45.0%, while *Capsicum annuum* was less effective. The "Danacha" variety of yam was the most vulnerable to beetle damage. These findings demonstrate the potential for the powders of the two botanicals to protect stored yam chips from beetle infestation and damage. Finally, the study can potentially contribute to developing more sustainable and effective methods for safeguarding white yam chips against *R. dominica*. Our study provides valuable insights into using botanical powders as a safe and natural alternative to conventional insecticides.

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