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PROTECTIVE EFFECTS OF SELECTED ESSENTIAL OILS AGAINST PADDY RICE INFESTATION BY THE RICE WEEVIL, *Sitophilus oryzae* (COLEOPTERA: CURCULIONIDAE)

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ABSTRACT

Rice (*Oryza sativa* L.) is a staple food in Nigeria, but storage losses caused by the rice weevil, *Sitophilus oryzae* (L.), remain a major challenge. This study evaluated the susceptibility of different paddy rice varieties to *S. oryzae* and the repellency of selected plant essential oils under laboratory conditions. Eighteen paddy rice varieties—15 improved FARO and three local varieties—were obtained from the National Cereals Research Institute, Badeggi, and local farmers in Lafia. Essential oils from clove (*Syzygium aromaticum*), West African black pepper (*Piper guineense*), and ginger (*Zingiber officinale*) were extracted by hydro-distillation. *Sitophilus oryzae* adults were cultured for three generations before use. Rice varieties differed significantly in infestation susceptibility. FARO 37 was extremely susceptible, whereas FARO 30, 61, and 22 ranged from highly to slightly susceptible. Seven varieties were moderately to slightly susceptible, while seven others, including all local varieties, were non-susceptible with no adult emergence. Infestation caused significant differences in seed damage and weight loss; FARO 37 recorded the greatest losses, whereas local varieties and FAROs 32, 44, 50, and 57 recorded none. All essential oils significantly repelled *S. oryzae*, with repellency increasing with dosage. Ginger oil at 1.00 mg/20 g of paddy rice produced the highest repellency (92.22 %, Class V), followed by West African black pepper (85.56 %, Class V) and clove (77.78 %, Class IV), all significantly superior to the control (P<0.05). These findings indicate that resistant rice varieties and plant-derived essential oils offer sustainable, eco-friendly options for protecting stored rice against *S. oryzae*.

Keywords: Essential oils, Paddy rice varieties, Postharvest protection, Repellency, S*itophilus oryzae*

INTRODUCTION

One of the most consumed cereal foods globally is rice, which serves as a staple diet for nearly half of the human population (Tagliapietra *et al*., 2024). In terms of production volume, it ranks after wheat and maize (Chauhan *et al.*, 2017; Erenstein *et al*., 2022). Rice (*Oryza* spp.) is a major family member of the Poaceae, and two principal cultivated species, *Oryza sativa* L. and *Oryza glaberrima* Steud, are grown principally across Asia, and West Africa, respectively (Mohanty, 2013; Udayangani, 2023). The cultivation of rice in Nigeria traces back to approximately 1,500 BC according to Ajala and Gana (2015). Global milled rice production as at 2025 was 555.5 million metric tonnes (MMT) (FAO, 2025a). This amount was largely contributed by countries like China, Indonesia, Bangladesh, India and Brazil. Nigeria has been reported to produce an estimated 7.9 million metric tonnes of paddy rice in the 2025/2026 season (USDA Foreign Agricultural Service [USDA-FAS], 2025). Nigeria is reportedly the highest consumer and importer of rice in Sub-Saharan Africa (Obi-Egbedi *et al*., 2012; Osagie, 2014); and is consumed in various traditional dishes such as jollof rice, tuwon shinkafa, and masa according to Evans *et al*. (2013).

The demand for rice consumption has increased due to global population growth, urbanization, and changes in family structures according to Bin-Rahman and Zhang (2022). Beyond food, the by-products obtained from rice are straw, husk, and bran which are used for livestock feed, fuel, and in cottage industries (Drake *et al*., 2002; Babatunde *et al*., 2021). Norton *et al.* (2010) and Hu and Xiong (2014) had reported that continued sustainable production of rice face challenges like reduced rainfall, soil salinity, and vulnerability to pests and diseases. Post-harvest losses in rice production have been reported to be as high as 20–40 % weight loss of grains due to insect infestation (Mondal *et al*., 2017). *Sitophilus oryzae* L. (rice weevil) is one of the most destructive storage pests, causing nutrient loss, contamination, and seed germination failure (Costa *et al*., 2016). Females lay eggs inside grains, and larvae feed internally, reducing grain quality (Demis & Yenewa, 2022).

Although pesticides are commonly used for pest control, they pose issues such as insect resistance, toxicity to non-target species, and environmental persistence (Barathi *et al*., 2024). Farmers globally spend billions on pesticides, yet according to FAO (2025b) pests still destroy over 40% of crops. Given the demand for pesticide-free grains globally, the use of botanicals have emerged as safer

alternatives as against synthetic insecticides (Isman, 2020; Bezabih *et al*., 2022; Yallappa *et al*., 2025). Plant-based insecticides are biodegradable, eco-friendly, and have long been used in traditional agriculture (Aziz *et al*., 2018). Essential oils from clove (*Syzygium aromaticum*), West African black pepper (*Piper guineense*), and ginger (*Zingiber officinale*) have shown insecticidal properties, including ovicidal, repellent, and antifeedant effects (Ajayi & Ogara, 2013; Hasan *et al*., 2018). Due to limited literature on the potency of oils extracted from these plant products against *S. oryzae* in stored paddy rice, this study was undertaken to evaluate the susceptibility of elite and local rice varieties paddy to the rice weevil infestation and to assess the protective potential of the essential oils extracted from clove, West African black pepper, and ginger.

MATERIALS AND METHODS

Experimental Location

The study was conducted at the Agronomy Research Laboratory, Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University, Keffi. The research site, Lafia, is situated at latitude 08.33°N and longitude 08.32°E in north-central Nigeria (Akomolafe & Rahmad, 2020). Experimental procedures were performed under ambient laboratory conditions, with an average temperature of 27±2 °C and relative humidity of 65±3 %.

Sources of Experimental Materials and Treatments

Paddy rice varieties

Eighteen paddy rice varieties (FARO 17, FARO 20, FARO 22, FARO 27, FARO 30, FARO 31, FARO 32, FARO 33, FARO 37, FARO 44, FARO 50, FARO 52, FARO 57, FARO 60 and FARO 61) for the experiment were obtained from the National Cereals Research Institute, Badeggi (NCRI), Niger State; and three local varieties Jamila, Lafia Sippi and Water proof were purchased from farmers in Lafia Nasarawa state at the end of the 2020 harvest season. All paddy rice collected were stored in the freezer at -20 ºC for 2 weeks in order to kill any insect eggs and adults that may have harboured inside the kernel. After 2 weeks the rice paddy was put in the desiccator in order to dissipate any moisture that would have been absorbed by the kernel. Thereafter, the rice paddy was kept in the laboratory cupboard in tightly sealed polypropylene sheet until needed for the experiment.

Procurement of edible spice plant materials

Dry 5 kg each of the seeds of clove, *Syzygium aromaticum* (L) Merr. and L.M. Perry, West African Black Pepper, *Piper guineense*, Schumach & Thonn., ginger rhizome, *Zingiber officinale* Roscoe were purchased from Lafia market in Nasarawa State. Each of these spices were cleaned, and sorted in order to obtain dirt free materials. The edible spices were macerated in a mortar with a pestle and thereafter milled into a semi fine powder using a kitchen Kenwood® blender according to the method of Ajayi and Lale (2001a).

Processing of the edible essential oil

The edible essential oil was extracted from the semi-fine powders of clove, *Syzygium aromaticum*, West African Black Pepper, *Piper guineense* and ginger rhizome, *Zingiber officinale*, at the Science and Technology Complex Laboratory (SHETSCO) Sheda, Abuja FCT using a glass steam essential oil distiller (Model EME31000/CEB) with a round bottom flask. The powder stock of clove, West African Black Pepper, and ginger were soaked with distilled water in a round bottom flask for 4 – 6 h and heated for 1 h at 100 ºC. The extracted oil and water were removed from the receiving flask and the essential oil was transferred via a separating funnel. Each extracted edible spice oil (ESO) was stored in a sample bottle, labelled and kept in the laboratory cupboard until when needed for the experiment (Jayasundara & Arampath, 2021; Katekar, 2023; Awojide *et al*., 2024).

Sourcing and insect culturing

The initial parent stock of the rice weevil that was used for the experiment were sourced from an already infested polished rice obtained from rice merchants at Lafia market. This batch of insect was re-infested on 750 g of polished rice (Jamila variety) in a transparent polypropylene jar covered with Muslin cloth and this was put in five different jars and kept in the laboratory. Emerging adults from the culture was re-infested following the method described above for upwards of three generations in order to acclimatize the insects to laboratory conditions. Adult that emerged from the third generations were used for the study following the methods described by Okpile *et al*. (2021) and Abd El Salam *et al*. (2024).

Treatment Plan and Experimental Design

Determination of relative susceptibility test of the paddy rice to *S. oryzae*

Twenty grams of paddy rice were measured into a 50 g plastic vial fitted with a lid. Subsequently, five pairs of adult *Sitophilus oryzae* were introduced into each vial and the containers were securely covered. The sex of the insects was determined following the procedure outlined by Odeyemi and Daramola (2000), while adult separation was carried out according to the method of Gvozdenac *et al*. (2020), based on rostrum length. The adult weevils were allowed to mate and lay eggs for 20 days, after which all insects (both live and dead) were carefully removed from the paddy rice samples.

Adult emergence count was taken for the first generation over a period of 30 days consecutively after the emergence of the first adult. Relative Susceptibility Index (RSI) was determined following the method used by Dobie (1974). The percentage weight loss and percentage seed damage were calculated following the method described by Ileke *et al.*, (2020) while severity seed damage was calculated following the method of Nyarko *et al*. (2022). The experiment was laid down in a complete randomized designed (CRD) and replicated three each.

Determination of repellency effect of the edible essential oil treatment on paddy rice

The repellency of the edible essential oils to adult *S. oryzae* was tested on each of the paddy rice using the Petri dish chamber test as described by Sighamony *et al*. (1984). The test arena was made of the 9 cm diameter Whatman No.1 filter paper divided into two pieces. The other half of the filter paper was taped to one half of the filter paper, creating a complete unit. The different edible essential oils (EEO) were dissolved in 2 ml of analytical grade acetone (0.25, 0.5, 0.75 and 1.0 mg, respectively). A uniform application of each concentration in one half of the filter paper disc was done, as much as possible, using the pipette. The other part of the filter paper remained untreated. Half of the paper was dipped in 2 ml pure analytical grade acetone in the control chambers and untreated in the other half. The acetone as the carrier, was left to evaporate before the introduction of the test insects to the Petri dishes. Subsequently, 30 adult *S. oryzae* of unsexed age, 2 – 3 days old, were inoculated at the centre of the Petri dish and the lid placed. Insects on the treated and untreated discs were counted after 30 min. The experimental set up was carried out in a complete randomized designed (CRD) and treatments replicated three times.

Data Collection and Analysis

Determination of relative susceptibility index

The relative susceptibility was calculated following the method of Dobie (1974) as follows:

$$\text{Relative Susceptibility index} = \frac{LnF1}{D} \; x \; \frac{100}{1}$$

Where: Ln is the natural logarithm, F_1 is the total number of first-generation emerged adults; D is the median development time (days from middle of oviposition period to emergence of 50 % of the F_1 progenies were taken as the median development time).

Determination of percentage weight loss

The initial weight of each paddy rice sample was taken to determine the percentage weight loss. The percentage reduction in weight was computed following the procedure described by Ileke *et al*. (2020) as shown below:

$$\text{Percentage weight loss (PWL)} = \frac{W1-W2}{W1} \; x \; \frac{100}{1}$$

Where W_1 = Initial weight; W_2 = Final weight

Determination of Percentage Seed Damage Loss

The percentage seed damage was determined using the procedure described by Ileke *et al*. (2020) as shown below:

$$\%\text{Seed damage} = \frac{\text{Number of seeds damaged}}{\text{Total number of seeds}} \; x \; \frac{100}{1}$$

Determination of severity of seed damage

The severity of seed damage was calculated following the method described by Nyarko *et al*. (2022) as follows:

$$\text{Severity of seed damage} = \frac{\text{Number of F1 Progeny Adults}}{\text{Number of damaged seeds}}$$

Repellency effect of edible essential oil

The number of adults repelled from the treated half disc of Whatman No. 1 filter paper 9 cm in the Petri dish was recorded and calculated according to the method of McDonald *et al*. (1970) as follows:

$$\text{Percent Repellency (PR)} = \frac{\text{Nc}-\text{Nt}}{\text{Nc}+\text{Nt}} \; x \; \frac{100}{1}$$

Where: Nt = number of insects present on the treated half disc; Nc = Number of insects present on the untreated half disc

The percentage class of repulsion (CR) was classified according to McDonald *et al*. (1970) as follows:

0 > 0.01 = 0
0.1 to 20 = I
20.1 to 40 = II
40.1 to 60 = III
60.1 to 80 = IV
80.1 to 100 = V

Statistical Analysis

All data collected were analysed using one-way and two-way ANOVA. Differences between mean responses were compared using the Least Significant Difference (LSD) statistic ($P < 0.05$). All data with zeros were transformed using the square root method ($\sqrt{(x + 0.5)}$). All percentage data were transformed before analysis. Data analysis was carried out with STAR® (2013) analytical package.

RESULTS AND DISCUSSION

Susceptibility of Elite and Local Varieties of Paddy Rice to the Rice Weevil, *S. oryzae* L.

The results of the study presented in Table 1 revealed the level of susceptibility responses of fifteen (15) elite and three (3) local varieties of paddy rice to infestation by the rice weevil, *Sitophilus oryzae.* The Susceptibility index was classified according to hierarchy from the highest to the lowest level as: extremely susceptible (7.09) > highly susceptible (4.23) > slightly susceptible (3.19) > moderately susceptible (1.78) > susceptible (0.89) > non-susceptible (0.00).

The three local varieties, Jamila, Lafia-Sippi and Water Proof and FARO 32, FARO 44, FARO 50 and FARO 57 were found to be non-susceptible (0.00) respectively, as there were no adult emergence recorded from them and hence were significantly different (<0.05) from the rest of the varieties. There was, however, no statistical differences ($P \geq 0.05$) between susceptibility indices recorded for FARO 60 (1.78), FARO 52 (0.89), FARO 33 (0.89), FARO 31 (0.89), FARO 27 (0.89), FARO 20 (1.78) and FARO 17 (1.78), respectively. FARO 37 (7.09), judged to be extremely susceptible, was significantly (<0.05) different from FARO 22 (3.19), FARO 30 (4.23) and FARO 61 (4.23) were not statistically different from each other ($P = 0.05$). The level of susceptibility of the varieties can thus be ranked as follows: FARO 37 (Extremely susceptible) > FARO 30, 61 (Highly susceptible) > FARO 22 (Slightly susceptible) > FARO 17, 20, 60 (Moderately susceptible)

> FARO 27, 31, 33, 52 (Susceptible) > FARO 32, 44, 50, 57, Jamila, Lafia-Sippi, Water Proof (Non-susceptible).
The findings of this study revealed that the susceptibility of the elite and local rice varieties evaluated against the rice weevil (*Sitophilus oryzae*) was classified into six categories based on the hierarchical susceptibility index (SI): extremely susceptible > highly susceptible > slightly susceptible > moderately susceptible > susceptible > non-susceptible. The results of this study align with the findings of Hussain and Nasr (2015), who reported comparable outcomes in their investigation on the susceptibility of rice to *Sitophilus oryzae* in Egypt. Swella and Mushobozy (2009) and Ojumoola and Adesiyun (2015) had also shown that elite varieties of grains are susceptible to varying degree of damage to stored product pests in an experiment carried out on some elites of cowpea infestation to *Callosobruchus maculatus*.
Faro 37 an elite variety exhibited extreme level of susceptibility due to high presence of adult emergence, and insect perforation on the paddy. The non-susceptible varieties which include both elite and local F32, F44, F50, F57, Jamila, Lafia-Sippi, Water Proof were not susceptible to the rice weevil after emergence. This maybe as result of some deterrent factors such as hardness of the outer coat, size of the paddy rice, and chemical inhibitors as stated by various researchers (Ajayi & Lale, 2001b; Jha *et al*., 2012; Ribeiro *et al*., 2012). However, these aspects were not evaluated in this study. The present study however, established that many of the elite varieties were not completely free from infestation by the adult *S. oryzae*. This is consistent with the reports of Astuti (2019) and Majd-Marani *et al*. (2023).

Table 1: Susceptibility of some elite and local varieties of paddy rice to the rice weevil, *S. oryzae* L.

Variety	*Susceptibility Index (SI)	Susceptibility Status	Variety Status
FARO 37	7.09^{a}	Extremely susceptible	Elite
FARO 30	4.23^{ab}	Highly susceptible	Elite
FARO 61	4.23^{ab}	Highly susceptible	Elite
FARO 22	3.19^{bc}	Slightly susceptible	Elite
FARO 17	1.78^{bcd}	Moderately susceptible	Elite
FARO 20	1.78^{bcd}	Moderately susceptible	Elite
FARO 60	1.78^{bcd}	Moderately susceptible	Elite
FARO 27	0.89^{cd}	Susceptible	Elite
FARO 31	0.89^{cd}	Susceptible	Elite
FARO 33	0.89^{cd}	Susceptible	Elite
FARO 52	0.89^{cd}	Susceptible	Elite
FARO 32	0.00^{d}	Non-susceptible	Elite
FARO 44	0.00^{d}	Non-susceptible	Elite
FARO 50	0.00^{d}	Non-susceptible	Elite
FARO 57	0.00^{d}	Non-susceptible	Elite
Jamila	0.00^{d}	Non-susceptible	Local
Lafia-Sippi	0.00^{d}	Non-susceptible	Local
Water proof	0.00^{d}	Non-susceptible	Local

* = Susceptibility Index of three replicates; Means having the same letter within a column do not differ significantly at the 5 % probability level, based on the Least Significant Difference (LSD) test (P < 0.05)

Effect of Adult *S. oryzae* L. Infestation on Seed Weight Loss, Seed Damage and Severity Seed Damage of Elite and Local Varieties of Paddy Rice Infested in Lafia

The effect of infestation of adult *S. oryzae* on fifteen elite paddy rice and three local varieties is shown in Table 2. The mean percentage weight loss recorded on the various paddy rice showed that there were no significant differences (P≥0.05) between FAROs 30, 32, 44, 50, 57, Jamila, Lafia-Sippi, and Water proof (0.00), respectively and these were statistically different from weight loss recorded in FARO 50 (0.07) and FARO 57 (0.20); FARO 33 (1.07), FARO 52 (0.93); FARO 31 (1.47) that were not all statistically different (P≥0.05) from each other, but were all significantly different from the weight loss recorded on FAROs 20 (2.40), 17 (2.47) and FARO 60 (2.67) but were not significantly different (P≥0.05) from each other but were significantly different (P<0.05) from FARO 22 (4.80) which was also significantly from FARO 61 (14.07), and from FARO 27 (16.20) and the largest weight loss was recorded from FARO 37 (20.67) which was significantly different (P≤0.05) from all the paddy varieties.
Table 2 also showed the mean percentage seed damage and indicated that no seed damage were recorded on FAROs 30, 32, 44, 50, Jamila, Lafia-Sippi, and Water proof (0.00). However, these were significantly different (P<0.05) from FAROs 31 (2.78) and 33 (2.76) but were not statistically different from each other but were significantly different from FARO 27 (6.24) which was not significantly different (P≥0.05) from FARO 22 (5.84) and FARO 20 (5.26). FARO 17 (4.90) was not significantly different from FARO 20 (5.26) but were significantly different from FARO 61 (7.26) while all were significantly different (P<0.05) from FARO 37 (9.25) which recorded the highest mean percentage seed damage.
The mean seed severity damage shown in Table 2 indicated that paddy rice varieties FAROs 30, 32, 44, 50, Jamila, Lafia-Sippi, and Water proof (0.00) were not significantly different (P≥0.05) from each other and these were statistically different (P≥0.05) from FAROs 27 (0.19), 31 (0.18), 52 (0.16), 61 (0.16) while these were also not significantly different from FAROs 17 (0.21), 20 (0.23), 33 (0.20), 37 (0.28), 57 (0.23) and 60 (0.26). FARO 22 (0.23) was found to be significantly different (P<0.05) from all the other varieties.
Varieties that are infested by stored product pests are subjected to weight loss and hence seed damage. FARO 37 recorded the highest percentage mean weight loss of 20.67%. This is in consonance with the results of Majd-Marani *et al*. (2023) who reported a percentage weight loss of 11 – 33% on rice infested by *S. oryzae*. The results are also is in agreement with the reports of Ileke *et al*. (2020) who also reported weight loss of up to 65% on maize varieties infested by the *Sitophilus zeamais* Motz. The quantum of seed damages as observed in this study in an agreement with earlier reports by Longstaff (1981), Devi *et al*. (2017) and Bezabih *et al*. (2022) that indicated that the genus *Sitophilus* spp. can wreak serious devastation on the cereals.

Stored grains that suffer serious weight loss have been reported conversely to be damaged in relation to the weight loss suffered and hence have higher degree of damage severity. FARO 37 had the highest percentage weight loss recorded, and hence, the highest percentage seed damage and severity. This is in consonance to the reports of some authors such as Hussain and Nasr (2015), Sakadzo and Kugedera (2021) and Nyarko *et al*. (2022) who reported that the higher the weight loss of a seed during storage so also is higher the likelihood of the percentage seed severity. Increase in time of storage, condition of storage, and availability of food has also been reported to be a factor that contributes to stored products being infested by stored pests (Astuti, 2019). These factors were however, not evaluated in this study.

Table 2: Effect of adult *S. oryzae* L. infestation on seed weight loss, seed damage and severity seed damage of elite and local varieties of paddy rice infested in Lafia

Variety	*Mean Percentage Weight Loss (g)	Mean Percentage Seed Damage	Mean Severity Seed Damage	Variety Status
FARO 17	2.47^{f}	4.90^{f}	0.21^{ab}	Elite
FARO 20	2.40^{f}	5.26^{ef}	0.23^{ab}	Elite
FARO 22	4.80^{e}	5.84^{de}	0.23^{ab}	Elite
FARO 27	16.20^{b}	6.24^{d}	0.19^{ab}	Elite
FARO 30	15.00^{c}	8.33^{b}	0.25^{ab}	Elite
FARO 31	1.47^{g}	2.78^{hi}	0.18^{ab}	Elite
FARO 32	0.00^{j}	0.00^{k}	0.00^{c}	Elite
FARO 33	1.07^{gh}	2.76^{hi}	0.20^{ab}	Elite
FARO 37	20.67^{a}	9.25^{a}	0.28^{ab}	Elite
FARO 44	0.00^{j}	0.00^{k}	0.00^{c}	Elite
FARO 50	0.00^{j}	0.00^{k}	0.00^{c}	Elite
FARO 52	0.93^{ghi}	3.51^{gh}	0.16^{bc}	Elite
FARO 57	0.00^{j}	0.00^{k}	0.00^{c}	Elite
FARO 60	2.67^{f}	5.10^{ef}	0.26^{ab}	Elite
FARO 61	14.07^{d}	7.26^{c}	0.16^{bc}	Elite
Jamila	0.00^{j}	0.00^{k}	0.00^{c}	Local
Lafia-Sippi	0.00^{j}	0.00^{k}	0.00^{c}	Local
Water proof	0.00^{j}	0.00^{k}	0.00^{c}	Local

* = Means are calculations based on three replicates; Means having the same letter within a column do not differ significantly at the 5 % probability level, based on the Least Significant Difference (LSD) test ($P < 0.05$)

Effect of concentration rates on the mean percentage number of adult rice weevil, *Sitophilus oryzae* L. repelled and Classification of Repellency by the three edible essential oils infesting paddy rice

The edible essential oils extracted from clove, *S. aromaticum*, West African Black pepper (WABP), *P. guineense*, and ginger, *Z. officinale* were used to determine the repellent effect of the oils on the rice weevil, *S. oryzae* as shown on Table 3. The results of the observation showed that the three edible essential oils significantly ($P<0.05$) repelled the rice weevil at higher dosage rates when compared to lower dosage rates. Extracts from clove oil at the dosage rate of 1.00 mg repelled higher number of adult *S. oryzae* (77.80) significantly ($P<0.05$) more than all the dosage rates, 0.75 (71.11), 0.50 (63.33) and 0.25 (63.33) mg and the control (53.33) while 0.25 mg and the control were not significantly different from each other ($P\geq0.05$). Higher number of adult *S. oryzae* was repelled more in treatment with 1.00 mg (85.56) of WABP but this was not significantly different ($P\geq0.05$) from treatment with 0.75 mg (84.44); and were significantly different ($P<0.05$) from treatments with 0.50 (61.11) and 0.25 mg (41.11) which were all significantly different ($P<0.05$) from the control (33.33). The repellency effect of treatment with ginger oil showed that, all the oil treatments were significantly different ($P<0.05$) from each other with treatment with 1.00 mg (92.22), 0.75 mg (84.44), 0.50 mg (74.45), 0.25 mg (61.11) and the control (33.33), respectively. The highest repellency effect was recorded with the use of ginger oil with 92.22 % repellency which was significantly different from oil treatment with WABP (85.56 %) and that of clove (77.78 %). The effect of treatment with WABP oil was also significantly different ($P<0.05$) when compared with the effect of clove oil.

Table 3: Effect of concentration rates on the mean percentage number of adult rice weevils, *Sitophilus oryzae* L. repelled by three edible essential oils infesting paddy rice

Dosage (mg/30 cm^2)	Edible Essential Oil Type			
	Clove	WABP*	Ginger	Mean
0.25	53.33^{b}	41.11^{b}	61.11^{b}	51.85
0.50	63.33^{c}	61.11^{c}	74.45^{c}	66.30
0.75	71.11^{d}	84.44^{d}	84.44^{d}	80.00
1.00	77.78^{d}	85.56^{d}	92.22^{e}	85.19
0.00 (Control)	32.29^{a}	33.33^{a}	33.33^{a}	32.98
Mean	59.57	61.11	69.11	

+ = Repellence percentages of three replicates; *WABP = West African black pepper; Means having the same letter within a column do not differ significantly at the 5 % probability level, based on the Least Significant Difference (LSD) test ($P < 0.05$)

The repellency classification of the three edible essential oils on adult *S. oryzae* is shown in Table 4. The results showed that clove oil at the dosage rate of 1.00, 0.75 and 0.50 mg elicited Class IV (77.78, 71.11, 63.33) repellency, respectively; while WABP and ginger oil at the dosage rate of 1.0 mg were classified as Class V (85.56 and 92.22), respectively. All the three oils clove (53.33), WABP (61.11) and ginger (41.11) recorded Class III when used at the dosage rate of 0.25 mg. However, ginger at the rate of 0.50 mg was Class III (61.11). WABP (74.45) on the other hand was classified as Class IV at the dosage rate of 0.50 mg. All the control treatments were classified as Class II.

Table 4: Classification of repellent action of the three edible essential oils against the rice weevils, *Sitophilus oryzae* L. infesting paddy rice

Dosage (mg/30 cm^2)	Edible Essential Oil Type					
	Clove		WABP*		Ginger	
	Mean % Repellency	[a]Repellency Class	Mean % Repellency	Repellency Class	Mean % Repellency	Repellency Class
0 (Control)	32.29	II	33.33	II	33.33	II
0.25	53.33	III	61.11	III	41.11	III
0.50	63.33	IV	74.45	IV	61.11	IV
0.75	71.11	IV	84.44	V	84.44	V
1.00	77.78	IV	85.56	V	92.22	V

*WABP = West African black pepper; [a]Repellency Class: Class II = 20.1 – 40 %; Class III = 40.1 – 60 %; Class IV = 60.1 – 80 %; Class V = 80.1 – 100 %

Edible essential oil extracted from clove, WABP and ginger were used to repel adult *S. oryzae* on paddy rice variety showed varying degrees of repellency by these oils. In an earlier report, Ajayi and Lale (2001b) reported that oils extracted from clove, WABP and ginger caused repellency classes of II – V on adult *Callosobruchus maculatus* at concentrations of 50 – 250 mg/30 cm^2. As observed in this study, repellency classes of III – V was achieved at concentrations of 0.25 – 1.00 mg/30 cm^2 however at lower dosage rates and on different stored produce and stored pests. The results were also in agreement with the report of Asawalam (2006) who reported that *Piper guineense* oil evoked repellency class V on maize weevil. It is also in consonance with an earlier reports of Bandara and Senevirathne (2022) who reported that clove oil evoked class V on the rice weevil, *S. oryzae* and that of Suthisut *et al*. (2011) who reported ginger oil evoked class V on the maize weevil, *S. zeamais* at higher dosage rates. As found out in this study for repellency, ginger oil seems to have contained higher repulsion ability than clove and WABP. This could be attributed to the chemical constituents inherent in the oil which might contain irritant and foul-smelling chemicals that have the ability to strongly repel stored product insect pests (Al-Harbi *et al*., 2021; Patiño-Bayona *et al*., 2021).

CONCLUSION

The results of this study revealed that botanical extracts are highly effective in protecting stored agricultural produce by reducing insect pest infestation, which remains a major challenge for small-scale farmers. The study revealed that some of the elite varieties (FAROs 32, 44, 50, 57) and the three local varieties Jamila, Lafia Sippi and Water proof can be recommended to farmers bearing in mind other agronomic characteristics on the field, as these can be recommended to farmers when storing paddy rice. Caution should however be exercised in storing FARO 37 that has been found to be extremely susceptible to *S. oryzae*, the rice weevil. All the botanical extracts were found to exhibit high repellency effect on the rice weevil albeit at high dosage rates. Highest repellency effect was recorded in ginger oil with 92.22 % repellency followed by WABP 85.56 % and clove 77.78 %. All the three oils, clove, WABP, and ginger recorded class II - V at dosage rates of 0.25, 0.50, 0.75 and 1.00 mg. Research has in recent years focus on the use of natural plant derivatives that are biodegradable and safe for use in the environment as alternative to synthetic pesticide which are more harmful to human health and the environment. The use of these botanical extracts would therefore play an important role in alleviating food shortage and enhance food security.

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