PAT December, 2024; 20(2): 74-87 ISSN: 0794-5213

Online copy available at www.patnsukjournal.org

Publication of Nasarawa State University, Keffi

ORIGINAL ARTICLE

POST-OVIPOSITION EFFICACY OF SLOW RELEASE PELLETIZED ESSENTIAL OILS IN MANAGEMENT OF BRUCHID (*Callosobruchus maculatus* F.) INFESTATION OF COWPEA (*Vigna unguiculata*. L. Walp.) UNDER DIFFERENT STORAGE DEVICES

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Abstract

This study evaluated the effectiveness of slow-release pelletized edible essential oils clove (*Syzygium aromaticum*), West African Black pepper (*Piper guineense*), and ginger (*Zingiber officinale*) alongside a synthetic insecticide (Coopex Dust®) against *Callosobruchus maculatus*, a major pest of stored cowpea seeds. Conducted under ambient laboratory conditions at the Agronomy Laboratory, Faculty of Agriculture, Federal University of Lafia. The experiment used post-oviposition bioassay. Treatments included 0.25, 0.5, 0.75, and 1.0g doses per 50g seeds and a control. Storage devices tested were polypropylene sacks, clay pots, jerry cans, and galvanized tins. A 4×5×4 factorial design, completely randomized and replicated three times, was employed. Data were transformed and analyzed using Statistix 10® software. Significant differences ($P \leq 0.05$) were observed in the number of eggs laid, with clove-treated seeds significantly recorded the highest egg count (953.63), followed by west African black pepper (942.57), Coopex (942.03), and ginger slow release pelletize essential oil (938.9). Mortality rates also varied significantly across storage devices, with galvanized tins showing the highest insect mortality (0.03%), followed by jerry cans (0.02%), while polypropylene sacks and clay pots had lower mortality rates (0.018% and 0.022%, respectively). Ginger slow release pelletize essential oil 1.0g dosage showed the highest insect mortality (0.03%), matching Coopex at the same dose, while the lowest mortality was recorded in control treatments of clove and WABP (0.013%). Grain weight loss was significantly lower in cowpea seeds treated with 1.0 g ginger (3.51%) compared to control clove treatment 0.0 g (46.87%), Coopex dust control 0.0g (45.73%) and cowpea treated with clove slow release pelletize essential oil at 0.25g (27.56%). Additionally, adult insect emergence value was highest in seeds stored in polypropylene sacks treated with West African black pepper (652.07%) and lowest in galvanized tins treated with ginger slow release pelletize essential oil (304.67%). Overall, higher slow release pelletize essential oil concentrations 1.0g effectively reduced egg laying, mortality, grain weight loss, and adult emergence. Galvanized tins outperformed other storage devices in protecting cowpea seeds. The study recommends using ginger slow release pelletize essential oil-based in airtight containers such as galvanized tins to improve storage and minimize post-harvest losses.

Keywords: Cowpea weevil, essential oils, grain damage, weight loss, grain perforation

Introduction

Cowpea (*Vigna unguiculata* L. Walp) is a crucial crop, especially in tropical and subtropical regions like West Africa, where it is vital for food security and income generation among smallholder farmers. Cowpea high protein content and ability to fix nitrogen, enhancing soil fertility, make it an important crop in these regions (Adebooye and Singh, 2020). However, the cowpea weevil (*Callosobruchus maculatus*), commonly known as the bruchid beetle, poses a significant threat to cowpea production and storage, severely impacting both seed quality and quantity. The infestation by *C. maculatus* begins when adult females lay their eggs on the seed surface. After hatching, the larvae burrow into the seeds and consume the endosperm, leading to significant seed damage and weight loss. The seeds are further devalued as they become unsuitable for planting or consumption, especially in cases of severe infestation. Untreated cowpea seeds can experience up to 100% damage during storage, which poses a serious threat to food security and economic stability in affected areas (Akah and Onyeka, 2017).

This issue calls for effective post-harvest management strategies to prevent bruchid infestation in stored cowpea seeds. Traditionally, synthetic chemical insecticides have been the primary method for controlling bruchid infestations in stored cowpea seeds. These insecticides have proven effective in managing pest populations; however, they also present a range of challenges. Among these are the development of resistance in pests, the presence of chemical residues on food products, and the potential for environmental contamination (Olukolu *et al*., 2021). As a result, there has been increasing interest in finding more sustainable, environmentally friendly pest control alternatives, with plant-based insecticides emerging as a promising option. Plant oils and essential oil extracts, which contain bioactive compounds such as terpenes, phenols, and alkaloids, have been identified for their insecticidal, ovicidal and repellent properties (Kostyukovsky *et al*., 2002). These natural products are biodegradable, safe for human use, and pose minimal risks to the environment, making them an attractive alternative for managing bruchid infestations in stored grains (Adedire *et al*., 2020).

Most of the research on plant oils has focused on their pre-oviposition effects, preventing adult pests from laying eggs. However, there is a growing interest in their post-oviposition efficacy and how well these oils can control pests after eggs have been laid, particularly by targeting stages such as larvae and pupae that are already developing inside the seeds. The challenge with post-oviposition control is that larvae burrow into the seeds, making them less accessible to traditional insecticides that rely on contact. This has led to a growing focus on plant oil treatments that can penetrate the seed coat and target developing pests. Neem oil (*Azadirachta indica*), for instance, has been extensively studied for its ability to reduce egg viability and inhibit the growth of larvae and pupae due to its active compound, azadirachtin. Research shows that neem oil applied after eggs have been laid significantly reduced the emergence of adult bruchids, offering a long-term protection strategy for cowpea seeds (Onwuka and Nelson, 2020; Rana *et al*., 2021). Eucalyptus oil (*Eucalyptus* spp.), another effective plant oil, contains compounds such as 1, 8-cineole and limonene, which have been shown to exert fumigant toxicity against stored-product pests. Studies demonstrated that eucalyptus oil reduced larval survival and prevents adult emergence from seeds that were treated post-oviposition (Musa and Olayemi, 2013). Similarly, clove oil (*Syzygium aromaticum*), rich in eugenol, exhibited strong ovicidal and larvicidal properties, making it an effective post-oviposition treatment (Oyelami *et al*., 2022).

In addition to the choice of treatment, the type of storage device used can significantly influence the effectiveness of plant oils in managing bruchid infestations. Many farmers in tropical regions rely on traditional storage methods, such as jute sacks, clay pots, or woven baskets, which are porous and allow pests easy access to the seeds (Imbuhila *et al*., 2019). These storage devices offer little protection, and pest infestations remain a persistent problem. More recently, hermetic storage systems, such as airtight plastic containers and hermetic bags, have been introduced as effective tools for controlling stored-product pests. Hermetic storage works by creating an oxygen-deprived environment that inhibits insect respiration and development (Kiri *et al*., 2023). Combining plant oils with hermetic storage systems has been shown to improve pest control by reducing oil volatilization and prolonging insecticidal activity (Srivastava and Ahmad, 2014).

This combined approach offers a more sustainable and effective solution for managing *C. maculatus* infestations in stored cowpea seeds hence, this study aims at evaluating the post-oviposition insecticidal efficacy of selected three plant oil extracts (e.g. ginger slow release pelletize essential oil, west African black pepper oil, and clove oil) in reducing egg viability, larval development, and adult emergence of *C. maculatus* in infested cowpea seeds, assessing the comparative effectiveness of different storage devices (e.g., polypropylene sacks, clay pots, galvanized tin and jerry cans) in combination with plant oil treatments for controlling bruchid infestation and preventing seed damage during cowpea storage and to investigate the potential synergistic effects of combining plant oil extracts with different storage systems in enhancing long-term protection of cowpea seeds against bruchid infestation and minimizing post-harvest losses.

Material and Methods

The research was conducted in the Agronomy Laboratory at the Federal University of Lafia, located in the Southern guinea Savanna agro-ecological zone of Nigeria. The specific coordinates of the study site are 8°30′22″N and 8°31′22″E (Jayeoba, 2013). The cowpea seed bruchid (*Callosobruchus maculatus*) was collected from already infested cowpea. These insects were cultured in glass jars filled with pristine cowpea seeds to create a pure inoculum for the experiment. The culture was maintained for five generations to ensure that the insects were acclimatized before the experiment commenced. The cowpea variety, Kananado was purchased from the Lafia main market, Nasarawa State, and was put in the freezer (-18^oC) after sorting to disinfest it against any inherent eggs or larva in the seed. After five days, the seeds were equilibrated to laboratory conditions and stored in Kilner jars until use. The storage devices, jerry cans (1ltr), sewn polypropylene sacks (5 X 5 cm with a zip lock), galvanized tins (250g size), and clay pots with cover (500g size) were purchased from the Lafia main market. Each device was modified to standard dimensions suitable for the experiment. The Slow Release Pelletized Edible Essential Oils (SRPEEOs) made from clove, ginger slow release pelletize essential oil, and West African black pepper were procured from the National Institute for Pharmaceutical Research and Development (NIPRD) in Abuja and the synthetic insecticides was obtained from the Food and Storage Reserve Department of the Federal Ministry of Agriculture and Food Security, Lafia Office, Nigeria. The experiment was laid out in a completely randomized design with three replications.

Post-oviposition application of Slow Release Pelletized Edible Essential Oils (SRPEEOs)

In this bioassay, ten pairs of adult *Callosobruchus maculatus* of 0 – 3 days were introduced into the different storage devices, each containing 50g of untreated cowpea seeds. The insects were allowed to lay eggs (oviposit) for five days, after which all insects were removed. The number of eggs laid in each replicate and treatment was counted and recorded. Following oviposition, each batch of cowpea seeds (now carrying bruchid eggs) was treated with identical doses (0.25, 0.5, 0.75, and 1g) of SRPEEOs made from ginger slow release pelletize essential oil, West African Black Pepper and Clove and Cypermethrin (Coopex Dust®) at the recommended dosage. Data were collected to monitor bruchid emergence by following standard procedures.

All adults that emerged in all the treatments were counted and recorded. Adult mortality was calculated based on actual physical mortality of the adults' insect at the time of recording, Abbott's (1925) formula was used to calculate the effect of edible essential oil on the mortality of adult *C. maculatus* in comparison to the mortality recorded in the control as follows:

$$Pt = \frac{Po - Pc}{100 - Po} \times 100$$

Where:

Pt = Corrected mortality (%)

Pc=Control mortality (%)

Po =Observed mortality (%)

The number of adult emergences was expressed in percentages following the method of Odeyemi and Daramola (2000) as follows:

$$\%\text{Adult emergence} = \frac{\text{Total number of adult emergence}}{\text{Total number of eggs laid}} \times 100$$

Initial weight of each legumes sample was taken to determine percentage weight loss. The percentage weight loss was calculated following the method described by Ileke *et al.* (2020) as follows:

$$\text{Percentage weight loss (PWL)} = W_1 - \frac{W_2}{W_2} \times 100$$

Where
W_1 = Initial weight
W_2 = Final weight

Bruchid Perforation Index (BPI)
This was adopted from Fatope *et al.* (1995) and expressed as:

$$BPI = \frac{\%\ \text{treated cowpea grains perforated}}{\%\ \text{control cowpea grains perforated}} \times 100$$

BPI value exceeding 50 was regarded as enhancement of infestation by the beetle or negative protectability of the extract tested.

Statistical Analysis

All data obtained were subjected to two-way ANOVA as the case may be and the differences between treatment means were separated using the least significant difference test at P≤0.05% probability level using STATISTIX 10 version (2018) analytical package.

Results

Effect of different treatments on cowpea weevil and cowpea seed

The results presented in Table 1 show significant differences (P≤0.05) among cowpea seeds treated with different slow release pelletized essential oils and Coopex. Cowpea seeds treated with clove slow-release pelletized essential oil significantly recorded the highest number of eggs laid by *Callosobruchus maculatus* (953.63), followed by cowpea seeds treated with West African black pepper (942.57), Coopex (942.03), and ginger (938.9). In terms of insect mortality, clove slow release pelletized essential oils cowpea-treated seeds also had significantly the highest mortality rate (0.023%), followed by cowpea seeds treated with West African black pepper (0.023%), Coopex (0.022%), and ginger slow release pelletized essential oils with the lowest mortality (0.020%). Adult insect emergence rates mirrored this trend, with clove slow release pelletized essential oils cowpea-treated seeds showing the significant highest insect emergence (62.13%), followed by West African black pepper slow release pelletized essential oils (61.67%), Coopex (61.56%), and ginger slow release pelletized essential oils (60.92%). Grain weight loss was significantly greatest in clove slow release pelletized essential oils cowpea-treated seeds (32.10%), followed by cowpea treated with west African black pepper slow release pelletized essential oils (31.63%), Coopex (30.59%), and ginger slow release pelletized essential oils cowpea-treated seeds with the lowest loss grain weight (28.79%). Regarding the weevil perforation index, clove treatment again recorded significantly the highest value (74.69%), followed by West African black pepper slow release pelletized essential oils (69.21%), Coopex (68.37%), and ginger slow release pelletized essential oils with the lowest index (67.86%).

Effect of different treatment concentrations on cowpea weevil and cowpea seed.

The result in table 1 revealed the effect of different treatment concentrations on cowpea weevil (*C. maculatus*) infestation and cowpea seed quality with significant differences (P≤0.05) across all treatment concentrations. Where cowpea seeds in the control group (0.0g) significantly recorded the highest number of insect eggs laid (957.33), while seeds treated with 1.0g had the lowest (936.10). Insect mortality rates were significantly highest at the 1.0g concentration (0.027%) and lowest in the control group (0.015%). Adult insect emergence was also significantly lower at 1.0g (45.03%) compared to the control (96.01%). Grain weight loss followed a similar trend: seeds treated with 1.0 g concentration had the least grain weight loss (17.05%), while the seeds in the control group showed significantly the highest (56.97%) Grain weight loss. Intermediate concentrations (0.25g and 0.5g) produced moderate mortality rates, adult emergence, and weight loss values. Furthermore, the weevil perforation index was significantly lower in seeds treated at 1.0g (53.98%) compared to control seeds (82.20%).

Effect of different storage devices on cowpea weevil and cowpea seeds.

The result revealed the effect of different storage devices on cowpea weevil (*C. maculatus*) infestation and cowpea seed quality. Results (Table 1) showed significant differences (P≤0.05) across all storage devices.

Where cowpea seeds stored in polypropylene sacks significantly recorded the highest number of eggs (1182.6), followed by cowpea stored in clay pots (1052.0), while galvanized tins and jerry cans had the lowest egg counts (337.5 and 805.1, respectively). Mortality rates also varied significantly (P≤0.05) among storage devices, with galvanized tins (0.025%) and jerry cans (0.023%) showing significantly higher insect mortality compared to polypropylene sacks (0.018%) and clay pots (0.022%). In terms of adult insect emergence, seeds stored in polypropylene sacks had the highest emergence rate (81.37%), followed by clay pots (60.09%), while galvanized tins (48.23%) and jerry cans (56.59%) showed lower emergence. Grain weight loss was significantly greater in polypropylene sacks (49.92%) and clay pots (30.42%) compared to galvanized tins (20.11%) and jerry cans (22.65%). Finally, the Percentage Weevil Perforation Index also differed significantly (P≤0.05), with the highest perforation recorded in polypropylene sacks (88.76%) and clay pots (81.44%), and the lowest in galvanized tins (50.14%) and jerry cans (59.79%).

Table 1. **Determination of Post-oviposition efficacy of pelletized essential insecticidal oils on infested Cowpea seeds against *C. maculatus***

Treatment	No of Eggs Laid	% Mortality	% Adult Emerged	%Weight Loss	% Weevil perforation Index (WPI)
Botanical Extracts					
Clove	953.63a	0.023a	62.13a	32.10a	74.69a
WABP	942.57b	0.023a	61.67a	31.63ab	69.21b
Ginger	938.98b	0.020a	60.92a	28.79c	67.86b
COOPEX	942.03b	0.022a	61.56a	30.59b	68.37b
LSD	**10.74**	**0.0073**	**1.40**	**1.10**	**1.87**
Concentration					
Control 0	957.33a	0.015c	96.01a	56.97a	82.20a
0.25	948.54ab	0.016bc	63.87b	34.24b	71.99b
0.50	940.35bc	0.024ab	54.07c	25.70c	63.20c
0.75	939.19bc	0.026s	48.87d	19.92d	58.78d
1.0	936.10c	0.027a	45.03e	17.05e	53.98e
LSD	**12.01**	**0.0081**	**1.57**	**1.23**	**2.10**
Storages					
PS	1182.6a	0.018b	81.37a	49.91a	88.76a
CP	1052.0b	0.022ab	60.09b	30.41b	81.44b
JC	805.1c	0.023ab	56.59c	22.65c	59.79c
GT	737.5d	0.025a	48.23d	20.11d	50.14d
LSD	**10.74**	**0.007**	**1.40**	**1.10**	**1.87**

Means with the same letter in the column are not significantly different at 5% level of probability using LSD Test (P≤0.05).

Post-oviposition effects on the Interaction Test Treatment*Concentration

The results presented in Table 2 indicate significant differences (P≤0.05) in the interaction effects between treatments and concentrations of the slow-release pelletized essential oils on the number of eggs laid by *Callosobruchus maculatus*. The highest number of eggs was recorded in the control groups of clove slow released pelletized essential oil at 0.0g concentration (993.75), followed by the control groups of West African black pepper slow released pelletized essential oil at 0.0 g (951.17). In contrast, cowpea seeds treated with ginger slow-release pelletized essential oil at 1.0 g significantly the lowest number of eggs count (933.00), followed closely by cowpea seeds treated with Coopex at 1.0g (934.17).

Similarly, significant differences (P≤0.05) were observed in the percentage mortality rates, where cowpea seeds treated with 1.0g concentrations of ginger slow-release pelletized essential oil and Coopex both recorded significantly the highest mortality rates (0.03%), compared to lower mortality rates in the control treatments of clove and West African black pepper slow-release pelletized essential oil at their control group 0.0g (both 0.01%).

This study also revealed significant differences in adult insect emergence (P≤0.05). Cowpea seeds treated with 1.0g of ginger slow-release pelletized essential oil recorded the lowest adult emergence rate (45.37%), followed by Coopex (44.62%) and West African black pepper (44.62%), whereas the highest adult emergence was recorded in untreated cowpea seeds with 0.0g of West African black pepper (96.97%) and clove (96.92%).

In terms of grain weight loss, significant differences ($P \leq 0.05$) were noted. Cowpea seeds treated with 1.0g of West African black pepper showed the lowest grain weight loss (15.51%), followed by treatments with 1.0g of Coopex (16.54%) and clove (17.58%). Conversely, untreated seeds showed the highest losses, with clove (0.0g) recording 57.87% and Coopex (0.0g) recording 57.73%.

Finally, the results for the Weevil Perforation Index also showed significant interaction effects ($P \leq 0.05$). The highest perforation index was found in untreated cowpea seeds: clove at 0.0 g (92.33%), West African black pepper at 0.0g (89.38%), and ginger at 0.0 g (88.76%). In contrast, the lowest perforation index was recorded in cowpea seeds treated with 1.0g of Coopex (51.91%), followed by 1.0g of West African black pepper (52.19%).

Table 2. Post-oviposition effects on the Interaction Test Treatment*Concentration

Treatment/ Conc.	**No of Eggs Laid**	**Treatment/ Conc.**	**% Mortality**	**Treatment/ Conc. (g)**	**% Adult Emerged**	**Treatment/ Conc. (g)**	**%Weight Loss**	**Treatment/ Conc. (g)**	**% Weevil perforation Index (WPI)**
Clove/0	993.75[a]	Ginger/1	0.03[a]	WABP/0	96.95[a]	Clove/0	57.87[a]	Clove/0	92.33[a]
WABP/0	951.17[b]	Coopex/1	0.03[a]	Clove/0	96.92[a]	Coopex/0	57.73a	WABP/0	89.38[b]
Ginger/0	950.33[b]	WABP/1	0.03[ab]	Ginger/0	96.91[a]	Ginger/0	56.45[ab]	Ginger/0	88.76[b]
Coopex/0	950.00[b]	Coopex/0.75	0.03[ab]	Coopex/0	93.26[b]	WABP/0	55.84[b]	Coopex/0	88.77[b]
Coopex/0.25	948.42[b]	Ginger/0.75	0.03[ab]	WABP/0.25	64.65[c]	Clove/0.25	39.56[c]	Clove/0.25	77.79[c]
Clove/0.75	947.00[b]	Clove/1	0.03[ab]	Coopex/0.25	64.58[c]	Ginger/0.25	35.82[cd]	WABP/0.25	70.62[d]
Ginger/0.25	945.83[b]	WABP/0.75	0.02[ab]	Clove/0.25	63.59[c]	Coopex/0.25	33.14[d]	Coopex/0.25	69.88[d]
WABP/0.5	945.42[b]	WABP/0.5	0.02[ab]	Ginger/0.25	62.67[c]	WABP/0.25	28.44[e]	Ginger/0.25	69.68[d]
Ginger/0.5	942.33[b]	Ginger /0.5	0.02[ab]	Clove/0.5	54.97[d]	Ginger/0.5	27.24[e]	Clove/0.5	68.97[d]
Coopex/0.5	941.50[b]	Coopex/0.5	0.02[ab]	Ginger/0.5	53.84[d]	Clove/0.5	25.78[ef]	Ginger/0.5	61.88[e]
Ginger/0.75	940.17[b]	Clove/0.75	0.02[ab]	WABP/0.5	53.79[de]	Coopex/0.5	25.48[ef]	Clove/0.75	61.41[e]
Clove/0.25	939.67[b]	Clove/0.25	0.02[ab]	Coopex/0.5	53.70[de]	WABP/0.5	24.28[fg]	WABP/0.5	61.12[e]
Clove/1	938.58[b]	WABP/0.25	0.02[ab]	WABP/0.75	50.70[ef]	Ginger/0.75	20.05[g]	Coopex/0.5	60.82[ef]
WABP/0.75	937.83[b]	Ginger/0.25	0.02[ab]	Ginger/0.75	48.81[eg]	Coopex/0.75	20.04[g]	WABP/0.75	60.73[ef]
Clove/0.5	937.75[b]	Clove/0.5	0.02[ab]	Coopex/0.75	48.56[fgh]	WABP/0.75	19.88[g]	Clove/1	58.97[efg]
WABP/0.25	937.58[b]	Coopex/0.25	0.02[b]	Clove/0.75	47.41[ghi]	Clove/0.75	19.71[g]	Ginger/0.75	56.65[fgh]
Coopex/0.75	936.42[b]	Coopex/0	0.02[b]	Clove/1	45.55[hi]	Ginger/1	18.57[g]	Coopex/0.75	56.32[ghi]
WABP/1	935.17[b]	Ginger/0	0.02[b]	Ginger/1	45.37[i]	Clove/1	17.58[gh]	Ginger/1	52.85[hij]
Coopex/1	934.17[b]	WABP/0	0.02[b]	Coopex/1	44.62[i]	Coopex/1	16.54[h]	WABP/1	52.19[ij]
Ginger/1	933.00[b]	Clove/0	0.01[b]	WABP/1	44.59[i]	WABP/1	15.51[h]	coopex/1	51.91[j]
LSD	**24.02**	**LSD**	**0.02**	**LSD**	**3.14**	**LSD**	**2.46**	**LSD**	**4.19**

Means with the same letter in the column are not significantly different at 5% level of probability using LSD Test (P≤0.05).

Where: WPI = Weevil perforation Index, SRPEEO = slow release pelletized essential oil. PS = Polypropylene sack, CP = Clay pot, JC = Jerry can, gT = galvanize tin, WABP = West African black pepper, Coopex = Cypermethrin dust, Trt. = treatment

The results presented in Table 3 revealed significant differences (P≤0.05) in the interaction effects between storage devices and treatments on the number of eggs laid by *Callosobruchus maculatus* on stored, treated cowpea seeds. The highest number of eggs was recorded on cowpea seeds stored in clay pots and treated with clove slow-release essential oil (1190.0), closely followed by those treated with West African black pepper (1182.5) and ginger slow-release pelletized essential oils (1181.0). In contrast, the lowest egg counts were observed on cowpea seeds stored in galvanized tins and treated with ginger (734.3) and West African black pepper (739.5).

Similarly, significant differences (P≤0.05) were observed in the interaction effects on the percentage mortality rate. The highest insect mortality rates were recorded on cowpea seeds stored in galvanized tins and treated with either Coopex dust or ginger slow-release essential oil (both at 0.03%), while the lowest mortality rates were found in cowpea stored in clay pots and polypropylene sacks treated with clove essential oil (0.02%).

Adult insect emergence also differed significantly across treatments. Cowpea seeds stored in polypropylene sacks and treated with clove recorded the highest emergence (84.05%), followed by those treated with West African black pepper (83.72%). Conversely, the lowest adult emergence was found in seeds stored in galvanized tins treated with ginger (47.12%) and Coopex (47.56%).

Furthermore, the interaction effects on grain weight loss were significant (P≤0.05). The highest weight loss was recorded in cowpea seeds stored in clay pots and treated with clove essential oil (52.13%), followed by seeds stored in polypropylene sacks treated with clove (51.75%). The lowest grain weight loss occurred in seeds stored in galvanized tins treated with ginger essential oil (18.68%) and those treated with clove (20.05%).

Finally, significant differences were found in the weevil perforation index. Cowpea seeds stored in polypropylene sacks and treated with Coopex exhibited the highest perforation index (98.99%), followed by those treated with West African black pepper (92.99%) and clove (92.99%). The lowest perforation index was recorded in seeds stored in galvanized tins treated with ginger essential oil (48.42%) and Coopex (48.57%).

Table 3. Post-Oviposition Treatments and Storage Devices Interaction Effects on Cowpea Seeds

Storages/ Trt.	**No of Eggs Laid**	**Storages/ Trt.**	**% Mortality**	**Storages/ Trt**	**% Adult Emerged**	**Storages/ Trt.**	**%Weight Loss**	**Storages/ Trt.**	**% Weevil peroration index**
CP/Clove	1190.0[a]	GT/Coopex	0.033[a]	PS/Coopex	84.05[a]	CP/Clove	52.13[a]	PS/Coopex	98.99[a]
CP/WABP	1182.5[a]	GT/Ginger	0.030[ab]	PS/WABP	83.72[a]	PS/ Clove	51.75[a]	PS/WABP	93.00[b]
CP/Ginger	1181.9[a]	GT/WABP	0.026[ab]	PS/Clove	79.55[b]	CP/Ginger	51.75[a]	PS/Clove	88.13[c]
CP/Coopex	1176.2[a]	GT/Clove	0.023[ab]	PS/Ginger	78.16[b]	CP/WABP	44.05[b]	PS/Ginger	88.07[c]
PS/Clove	1061.4[b]	JC/WABP	0.023[ab]	CP/Ginger	62.30[c]	CP/Coopex	33.19[c]	CP/Ginger	85.83[c]
PS/WABP	1052.3[b]	JC/Coopex	0.022[ab]	CP/WABP	60.52[cd]	PS/Ginger	32.09[c]	CP/WABP	79.56[d]
PS/Ginger	1049.6[b]	JC/Clove	0.022[ab]	CP/Coopex	60.40[cd]	PS/WABP	29.29[d]	CP/Coopex	73.60[e]
PS/Coopex	1044.6[b]	JC/Ginger	0.022[ab]	CP/Clove	58.64[de]	PS/Coopex	27.09[d]	CP/Clove	73.60[e]
JC/Clove	823.6[c]	PS/Coopex	0.022[ab]	JC/Ginger	58.47[de]	JC/Ginger	23.99[e]	JC/Ginger	61.67[f]
JC/Coopex	800.8[d]	PS/WABP	0.021[ab]	JC/Clove	57.13[ef]	JC/Clove	23.02[ef]	JC/Clove	61.33[f]
JC/WABP	799.0[d]	PS/Ginger	0.018[b]	JC/Coopex	54.69[f]	JC/Coopex	22.22[efg]	JC/Coopex	59.77[g]
JC/Ginger	796.9[d]	PS/Coopex	0.018[b]	JC/WABP	54.57[f]	JC/WABP	21.38[fg]	JC/WABP	56.40[g]
GT/Clove	741.8[e]	CP/WABP	0.018[b]	GT/WABP	49.73[g]	GT/Coopex	21.28[fg]	GT/WABP	51.88[h]
GT/WABP	739.5[e]	CP/Ginger	0.018[b]	GT/Clove	48.53[g]	GT/WABP	20.44[gh]	GT/Clove	51.67[h]
GT/Coopex	734.3[e]	PS/Clove	0.018[b]	GT/Coopex	47.56[g]	GT/Clove	20.05[gh]	GT/Coopex	48.57[h]
GT/Ginger	734.3[e]	CP/Clove	0.018[b]	GT/Ginger	47.12[g]	GT/Ginger	18.68[h]	GT/Ginger	48.42[h]
LSD	21.49	**LSD**	0.015	**LSD**	2.81	**LSD**	2.20	**LSD**	3.75

Means with the same letter in the column are not significantly different at 5% level of probability using LSD Test (P≤0.05).

Where: WPI = Weevil perforation Index, SRPEEO = slow release pelletized essential oil. PS = Polypropylene sack, CP = Clay pot, JC = Jerry can, gT = galvanize tin, WABP = West African black pepper, Coopex = Cypermethrin dust, Trt. = treatment

The results presented in Table 4 indicate significant differences (P≤0.05) in the interaction effects between storage device and treatment concentration on the number of eggs laid by *Callosobruchus maculatus* on treated cowpea seeds. The highest number of eggs laid was recorded in seeds stored in polypropylene sacks control group 0.0g (1186.7), followed closely by seeds stored in clay pots at the same control group 0.0g (1186.7). Conversely, the lowest egg counts were observed in seeds stored in galvanized tins treated at 1.0 g (722.8 eggs), followed by those stored in jerry cans at 1.0 g (738.9 eggs).

Similarly, significant differences (P≤0.05) were observed in the percentage mortality rates, where, cowpea seeds stored in galvanized tins at 1.0g treatment concentration recorded significantly the highest mortality rate (0.04%), followed by cowpea seeds stored in galvanized tins at 0.75g (0.03%). The lowest mortality rates were observed in cowpea seeds stored in polypropylene sacks and clay pots under the control treatment 0.0g (0.01% each).

The study also revealed significant differences in adult insect emergence (P≤0.05). Where the highest insect emergence rate was recorded in cowpea seeds stored in polypropylene sacks control group 0.0g (95.95%) and cowpea seeds stored in clay pots control group 0.0g (92.71%), while cowpea seeds stored in galvanized tins at 1.0g significantly had the insect lowest adult insect emergence rate (33.46%), followed by cowpea seeds stored in jerry cans at 1.0g (43.11%).

In terms of grain weight loss, significant differences (P≤0.05) were noted. Cowpea seeds stored in clay pots control groups 0.0g exhibited significantly the highest grain weight loss percentage (92.27%), compared to cowpea seeds treated at 0.25g and stored in both clay pots and polypropylene sacks (62.53%). The lowest grain weight loss was observed in seeds stored in galvanized tins at 1.0g (13.44%), closely followed by those treated at 0.75g (14.23%).

Finally, the results for the weevil perforation index also showed significant interaction effects (P≤0.05), with the highest weevil perforation index recorded in cowpea seeds stored in clay pots at 0.0g control group (100.63%), cowpea seeds stored in polypropylene sacks at 0.0g (98.75%), as well as cowpea seeds stored in jerry cans at 0.0g (98.57%). While cowpea seeds stored in galvanized tins treated at 1.0g concentration significantly had lowest weevil perforation index (29.64%), followed by cowpea seeds stored in galvanized tins at 0.75g (31.55%) and cowpea seeds stored in jerry cans at 1.0g treatment concentration (38.28%).

Table 4. Post-oviposition effects on cowpea storage devices on Comparisons Test of Storages*Concentration

Storages/ Conc. (g)	No of Eggs Laid	Storages/ Conc. (g)	% Mortality	Storages/ Conc. (g)	% Adult Emerged	Storages/ Conc. (g)	%Weight Loss	Storages/ Conc. (g)	% Weevil peroration index
PS/0	1186.7[a]	GT /1	0.04[a]	PS /0	95.95[a]	CP /0	92.267[a]	CP/0	100.63[a]
CP/0	1186.2[a]	GT /0.75	0.03[ab]	CP /0	92.71[b]	CP /0.25	62.533[b]	PS/0	98.75[b]
PS/0.25	1180.9[a]	JC /1	0.03[abc]	PS /0.25	89.32[c]	PS /0	55.717[c]	JC/0	98.57[b]
JC/0	1180.0[a]	GT /0.5	0.03[abc]	JC /0	79.73[d]	JC /0	43.771[d]	GT/0	98.87[b]
PS/0.5	1179.4[a]	GT /0.25	0.03[abcd]	PS /0.5	69.02[e]	CP /0.5	41.108[e]	PS/0.25	88.77[c]
JC/0.25	1061.9[b]	JC /0.75	0.03[abcd]	JC /0.25	60.99[f]	GT /0	36.125[f]	PS/0.5	88.68[c]
PS/0.75	1060.2[b]	JC /0.5	0.03[abcd]	PS /0.75	58.73[fg]	PS/0.25	31.692[g]	CP/0.25	86.46[cd]
CP/0.5	1046.6[b]	GT /0	0.02[bcd]	CP /0.5	57.07[gh]	CP /0.75	30.783[g]	PS/0.75	83.18[de]
CP/0.25	1046.2[b]	PS /0.75	0.02[abcd]	CP /0.25	56.98[gh]	PS /0.5	27.992[h]	PS/1	79.31[ef]
GT/0	1045.1[b]	PS /1	0.02[bcd]	GT /0	54.66[hi]	CP /1	22.900[i]	CP/0.5	77.31[f]
PS/1	836.6[c]	JC /0	0.02[bcd]	PS /1	53.83[i]	JC 0.25	21.533[ij]	CP/0.75	71.64[g]
CP/0.75	798.9[d]	JC /0.25	0.02[bcd]	CP /0.75	52.92[i]	GT /0.25	21.200[ij]	CP/1	67.42[h]
CP/1	798.0[d]	CP/1	0.02[bcd]	CP /1	49.72[j]	PS /0.75	19.658[jk]	JC/0.25	65.64[h]
GT/0.25	796.4[d]	PS /0.5	0.02[bcd]	GT /0.25	48.21[j]	JC /0.5	18.117[kl]	GT/0.25	50.74[i]
JC/0.5	795.5[d]	CP /0.75	0.02[bcd]	JC /0.5	48.19[j]	PS /1	17.025[lm]	JC/0.5	50.47[i]
GT/0.5	748.9[e]	CP /0.5	0.02[cd]	GT /0.5	46.99[j]	GT /0.5	15.567[mn]	JC/0.75	43.15[j]
JC/0.75	744.1[ef]	CP /0.25	0.02[cd]	JC /0.75	43.21[k]	JC /0.75	15.008[mn]	GT/0.5	39.56[jk]
JC/1	738.9[ef]	PS /0.25	0.02[cd]	JC /1	43.11[k]	JC /1	14.829[mn]	JC/1	38.28[k]
GT/0.75	732.8[ef]	CP/0	0.01[d]	GT /0.75	35.61[l]	GT /0.75	14.225[n]	GT/ 0.75	31.55[l]
GT/1	722.8[f]	PS/0	0.01[d]	GT /1	33.46[l]	GT /1	13.442[n]	GT /1	29.64[l]
LSD	**24.02**		**0.020**		**3.14**		**2.47**		**4.19**

Means with the same letter in the column are not significantly different at 5% level of probability using LSD Test ($P \leq 0.05$).

Where: WPI = Weevil perforation Index, SRPEEO = slow release pelletized essential oil. PS = Polypropylene sack, CP = Clay pot, JC = Jerry can, gT = galvanize tin, WABP = West African black pepper, Coopex = Cypermethrin dust, Trt. = treatment.

Discussion

The efficacy of various treatments including three slow-release pelletized edible essential oils and Coopex dust, in managing *Callosobruchus maculatus* infestation in cowpea seeds through post-infestation treatment revealed significant differences across treatments in egg-laying, mortality, adult emergence, grain weight loss, and the weevil perforation index. Clove slow release pelletized essential oil treatments resulted in the highest egg-laying, mortality, adult emergence, and perforation indices, while ginger slow release pelletized essential oil treatments exhibited the lowest mortality and grain weight loss. These results align with previous findings by Adedire *et al*. (2011) and Ibrahim *et al*. (2021), who attributed the insecticidal activity of clove and black pepper oils to bioactive compounds such as eugenol and piperine. Additionally, Opara and Eze (2022) suggested that incomplete egg suppression could explain the high adult emergence in clove-treated seeds.

Higher essential oil concentrations (1.0g) consistently reduced egg counts, adult emergence, weight loss, and weevil perforation index, as reported by Rios and Gonzalez (2022), Ahmed *et al*. (2021) and Jafari *et al*. (2020). Plant-based treatments, particularly clove and black pepper oils, outperformed Coopex dust in some parameters, supporting findings by Souto *et al*. (2022). Storage device significantly impacted treatment outcomes: polypropylene sacks allowed higher infestation and grain damage, while galvanized tins and jerry cans, being impermeable, enhanced insect mortality and reduced grain loss, consistent with Ajayi *et al*. (2021) and Derkyi and Opoku (2023). Mortality and adult emergence rates were significantly improved when treatments were applied in galvanized tins, in line with Sarfo *et al*. (2021) and Ahmed *et al*. (2021).

The untreated controls had the highest egg-laying rates, while 1.0g ginger slow release pelletized essential oil and Coopex treatments achieved the highest mortality and lowest adult emergence. These findings corroborate those of Aliyu *et al*. (2021) and Bashir *et al*. (2023) on the insecticidal effects of bioactive essential oils. Higher essential oil concentrations were associated with reduced grain damage, confirming studies by Ogunleye and Adeyemo (2021) and Kumar *et al*. (2022). The influence of storage materials combined with treatments, highlighting that clay pots alone were ineffective, while galvanized tins enhanced the efficacy of ginger slow release pelletized essential oil and black pepper. These results emphasize the crucial role of non-porous storage in pest management, as also noted by Aliyu *et al*. (2023) and Ogunleye and Adeyemo (2021).

The significant interactions between storage device, treatment type, and concentration on infestation parameters apparently indicated efficacy of the treatment materials. Untreated seeds in porous storage (polypropylene sacks and clay pots) experienced the highest infestation levels, whereas seeds treated with higher concentrations (1.0 g) and stored in galvanized tins exhibited the best protection. These findings reinforce assertions by Nwaubani *et al*. (2021), Hadi and Khan (2021), and Yusuf *et al*. (2023), highlighting that integrating potent bioactive treatments with impermeable storage is vital for minimizing cowpea seed losses during storage.

Conclusion

It was demonstrated that slow-release pelletized edible essential oils (SRPEEOs) and synthetic insecticides like Coopex dust® may be effectively used in controlling *C. maculatus* infestations in stored cowpea seeds. But their efficacy is highly dependent on concentrations used and the type of storage device. Higher concentrations of SRPEEO and synthetic insecticides provided better protection against post-oviposition biological activities of the cowpea seed bruchid. Airtight storage devices, such as galvanized tins and jerry cans, significantly enhanced the efficacy of both botanical and synthetic treatments by limiting insect development. In contrast, breathable storage devices like polypropylene sacks and clay pots were less effective in controlling pests, leading to higher egg-laying, adult emergence, seed weight loss, and weevil perforation. This study suggests that combining effective insecticidal treatments with airtight storage devices offers the most promising strategy for protecting cowpea seeds during storage. This approach can help reduce post-harvest losses, improve seed quality, and enhance food security in regions where cowpea is a staple crop.

Acknowledgement
The authors are sincerely grateful to the Nigeria Tertiary Education Trust Fund (TETFUND) for the sponsorship of this project via TETFUND National Research Fund (NRF) grant number TETF/ES/DR&D-CE/NRF2020/SETI/05/VOL.1.

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