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Efficacy of Diatomaceous Earth and *Vitellaria paradoxa* Seed Oil in Storage of Cowpea under Ventilated and Non-ventilated Conditions

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Authors' contributions

This work was carried out in collaboration between both authors. Author MOO designed the study, wrote the protocol and performed the statistical analysis while Author OPA collected the data, participated in the statistical analyses and prepared the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Storage of cowpea is highly constrained by insect pest infestation and losses caused by the cowpea weevil (*Callosobruchus maculatus*, F.) are high. Several methods have been used over the years to protect cowpea grains in storage, but the use of synthetic insecticides is very dominant and this has led to problems, such as the killing of non-target species, user hazards, harmful food residues, and evolution of resistance to chemicals. A search for alternative insect pest control methods which are relatively less harmful to the user and cheaper has become essential. The effectiveness of Diatomaceous earth (DE) and *Vitellaria paradoxa* seed oil (VPSO) for cowpea storage in polypropylene and jute bags under ventilated and non-ventilated storeroom conditions were investigated over three months period. Crude DE was applied at a dose rate of 1 g/kg of cowpea and a diluted concentration (10% v/v) of *VPSO* of 400 mL was mixed with 8 kg of cowpea. Live insect count, dead insect count, and germination percentage were assessed weekly while proximate analysis was carried out before and after storage. Mean live insect count increased in the ventilated store-room from 0.67±0.34 to 36.13±19.51insects/kg after 1 month and 3 months of storage

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respectively for untreated cowpea. Insect population in treated samples increased from 0.38±0.26to 24.78±23.33, and from 0.17±0.30 to 10.75±5.27 for DE and VPSO treated samples, respectively. In the non-ventilated storeroom, insect population increased from 0.33±0.26 to 36.96±19.09 for untreated cowpea, 0.17±0.20 to 33.08±30.07 for DE and 0.21±5.63 to 8.17±11.30 for VPSO treated cowpea. Based on insect count, both treatments were very effective in controlling cowpea weevil in the first two months of storage, however their potency reduced by the third month. The potency of DE deteriorated faster compared to VPSO however, DE treated cowpea was most effective for retaining seed germination in both ventilated and non-ventilated storerooms. Proximate analysis showed that cowpea treated with both treatments had similar nutrient composition after storage. Diatomaceous earth and *Vitellaria paradoxa* seed oil have potentials in their raw form for short term insect pest control in the storage of cowpea.

Keywords: Cowpea weevil; diatomaceous earth; Vitellaria paradoxa; seed germination; ventilation.

1. INTRODUCTION

Cowpea (*Vigna unguiculata*) is one of the most versatile food legumes in the tropical and subtropical regions of the world where it is cultivated [1]. Although indigenous to South-Eastern Africa, cowpea has spread worldwide and it is extensively cultivated and consumed in regions of Asia, South and Central America, the Caribbean, the United States, the Middle East and Southern Europe [2]. It is a major grain legume in Sub-Saharan Africa [3]. More than 5.4 million tons of dried cowpeas are produced worldwide, with Africa producing nearly 5.2 million while Nigeria, the largest producer and consumer, accounts for 61% of production in Africa and 58% worldwide [1,4].

Cowpea is cultivated for its leaves, green pods, grain and stem for livestock feed [5]. The plant tolerates drought, performs well in a wide variety of soils, and being a legume, it replenishes low fertility in soils when the roots are left to decay. Cowpea cultivation is predominantly associated with small-scale farmers in developing countries where it is intercropped with other plants because it is tolerant to moderate shade [6]. It also grows and covers the ground quickly, preventing erosion. The sale of the stems and leaves as animal feed during the dry season also provides a vital income for farmers [4]. The grains contain about 25% protein, several vitamins, and minerals which improve human nutrition and health status [3,7]. Cowpea plays an important role in the diet and economy of many small-scale farmers in Nigeria [8]. In Africa, humans consume the young leaves, immature pods, immature seeds, and mature dried seeds. The stems, leaves, and vines serve as animal feed and are often stored for use during the dry season. 52% of Africa's production is used for food, 13% as animal feed, 10% for seeds, 9% for other uses, and 16% is wasted [9].

Cowpea can be stored short term at about 12% moisture or less, with 8 to 9% recommended for long term storage [10]. Even when stored at the desired moisture content, insect infestation is still a major cause of losses. The primary insect pest causing losses to stored cowpea in West Africa is the cowpea weevil (*Callosobruchus maculatus*). It is a field-to-store problem as infestation begins in the field at low levels. After the crop is placed in storage, the insect population continues to grow to dangerous levels if unchecked. About 4 percent of the total annual production of cowpea or about 30,000 tonnes valued at over 30 million US dollars is lost annually to cowpea brunchids in Nigeria alone [11,12]. The problems during cowpea storage are further compounded by the indiscriminate use of synthetic insecticides which are expensive, deposit toxic residues in food, and constitute health hazards to consumers [13,14]. The indiscriminate use of these insecticides also leads to the development of pesticide resistance in insects [15,16]. This has necessitated research on the use of reduced-risk alternatives which are cheaper, available, and have no negative impacts on the environment and human health. Two of such control strategies under consideration for the last few decades are diatomaceous (DE) earth and plant materials.

DE is composed of fossilized skeletons of freshwater or marine diatoms that kill insects by abrading the cuticle and causing water loss through desiccation [17]. DE is ecologically sound and may be used alone or combined with botanicals for the control of stored grain insect pests [18,19,20,21,22]. The efficacy of diatomaceous earth against storage pests has been documented. DE products seem to be promising alternatives to pesticides because of their low mammalian toxicity, low or zero residual effects in food and are effective against the target pests [17]. For instance, [23] reported that Insecto and Bularafa DEs resulted in mortality of up to 73.6 and 61.2%, respectively in grains infested with *R. dominica* after 14 days. Similarly, [24] reported that Insecto and Bularafa DE treatments resulted in over 69% mortality and over 78% progeny suppression respectively against *R. dominica*. Moreover, [25] carried out a comparative analysis on DEs namely Insecto®, Bularafa, Abakire, Share and Kwami at 1000 ppm and findings showed that after 72 hours of exposure, the treatments resulted in mortalities of 90, 80, 76, 76 and 43% respectively against adult *C. maculatus* on Ife brown cowpea, and 86, 80,76, 73 and 73% respectively on IT98-12 cowpea variety.

Furthermore, plant materials are effective in controlling insect pests of stored cowpea. Plant materials such as Neem *(Azadiracta indica),* Black pepper *(Piper guinensis),* pepper fruit seed *(Dennettia tripetala)*, Physic nut (*Jatropha curcas*)*,* soya bean oil *(Glycine max)* and Lime peel oil have also been tested and recommended for grain storage [26,27,28]. These plant materials are cheap, locally available and environmentally friendly and nontoxic both to man and livestock. The application of oils of botanical origin (vegetable oils) to cowpea has been confirmed by many authors to be a method of protection against bruchid beetle attack [29]. It has also been reported that coconut oil, castor oil, soybean and mustard oils when mixed with cowpea, completely suppressed the survival of immature stages as well as adult emergence of various species of insects [30,31,32]. The efficacy of *Vitellaria paradoxa* seed oil (VPSO) on the oviposition, hatchability and emergences of *Callasobruchus maculatus* (F.) Coleoptera: Bruchidae) on treated cowpea seed was studied by [33] and it was concluded that VPSO has great potential for use as a plant-based bio-pesticide for controlling pulse beetle because significant reduction was observed in the hatching of the eggs in the grains treated with the oil (47.2%) when compared with the untreated control (86.3%).

It is typical of grain aggregators to store cowpea in non-ventilated storehouses in market areas, for periods up to six months. The quest for postharvest loss reduction and food safety requires in-depth knowledge on the comparative advantage of different alternatives which are harmless to the user, inexpensive, readily available, and indigenous to farmers, marketers and consumers of cowpea, given the recent push to reduce the use of synthetic pesticides in postharvest management of grains [34]. This study was therefore set up to carry out a comparative analysis of *Vitellaria paradoxa* seed oil and crude DE with respect to their storage efficacy on cowpea under ventilated and non-ventilated conditions.

2. MATERIALS AND METHODS

2.1 Study Area

The study conducted in Ilorin, the Kwara State of Nigeria at the Nigerian Stored Products Research Institute campus between October 2018 and January 2019. Mean ambient temperature and relative humidity in Ilorin during the study period were measured as 34.7^{o}C and 62.3% respectively.

2.2 Crop Variety

Cowpea seeds of the ‘Sokoto white’ variety, which were freshly harvested in early October 2018 was used. The grains were procured on special request directly from farmers in Gombe State, Nigeria and checked for insects and moisture. Moisture content was determined using the oven-dry method.

2.3 Experimental Design

The storage materials used were polypropylene bags and Jute bags while the storage treatments were Control (untreated), diatomaceous earth and shear butter (*Vittalaria paradoxa*) seed oil. Thus, the experimental design was set up as 3 treatments and two storage materials; replicated three times. Each treatment was made up of 8 kg of newly harvested dried cowpea grains in polypropylene bags and jute bags stored under ventilated and non-ventilated storerooms. The storerooms used were of equal size and were water and rodent proof, both measuring 3 × 4 × 3 m while the window size was 1.2 × 1.5 m. The ventilated storeroom windows were left open for cross ventilation while in the non-ventilated storeroom windows remained closed during the entire study period. The grains were thoroughly cleaned (manually) after which phosphine fumigation was carried out for 5 days before the study commenced.

2.4 Seed oil Formulation

Oil was extracted from the seed of *Vitellaria paradoxa* according to the method described by [35]. The dry seeds were roasted and pounded into a paste. The paste was mixed with cold water and allowed to stand for 3 hours. The mixture was sieved over a cheese cloth to obtain the filtrate. The filtrate was then heated in a pan at about 95°C until evaporation was completed and the crude oil extract was collected at the bottom of the container [33,35].

2.5 Diatomaceous Earth (DE) Formulation

Crude DE ore of freshwater origin was obtained from the Bularafa community in the Yobe State, Northern Nigeria. It was oven-dried at 40°C for six hours to 4.5% moisture content as recommended by [36], ground to dust by means of a laboratory mortar and pestle. It was sieved using a U.S. Standard sieve (No. 200) having a 0.074mm opening and kept in airtight Kilner jars for 24 hours. DE was applied at a dose rate of 1 g/kg of cowpea based on guidelines for the upper dose limit for Insecto™ (Insecto Natural Products, Costa Mesa, California), a commercially available refined DE product.

2.6 Sample Preparation

Diluted concentration (10% v/v) of VPSO of 400 mL was mixed with 8 kg of cowpea and replicated three times for both the ventilated and non-ventilated stores as described by [33]. The grains were mixed thoroughly with VPSO to ensure the proper coating of the seed with the oils. After shaking, the seeds were taken out and air dried for 1hr to evaporate the solvent as described by [37]. The DE was mixed thoroughly with the grains for 2-3 minutes to achieve a proper and uniform coating of the grains. Then the mixture was kept undisturbed for 30 minutes to allow the dust to settle. The control samples consist of three bags of 8 kg cowpea stored in the closed room and the room with an opened window.

2.7 Experimentation

Daily temperature and relative humidity were recorded in the storerooms using Lascar EL-USB-2 data loggers (Lascar Electronics, USA). Insect count was done weekly by taking 400 g samples from each treatment. Samples were sieved using an Endecotts™ 200mm diameter sieve with a 2 mm pore size. The number of dead and live insects was counted manually, extrapolated to insects/kg and recorded. Seed germination test was carried out for each treatment by sampling 10 seeds which were placed on moistened cotton wool in a 9 cm diameter disposable petri dish. Germination count was taken on the 7th day as recommended by [38]. Percentage seed germination was calculated using equation 1 by [39].

$$\text{Germination (\%)} = \frac{Ng}{Np} \times 100 \qquad (1)$$

Where:

N_g is number germinated
N_p is number planted

Proximate analysis (moisture, ash, fat, fibre, protein and carbohydrate) was carried out on samples before storage and after 12 weeks using the standard methods of [40]. Data were subjected to Analysis of variance (ANOVA) of two factor Completely Randomized Design (CRD) and means were separated by Duncan multiple range test using SPSS software.

3. RESULTS & DISCUSSION

3.1 Baseline Data

Observations from the baseline data taken on the grains before storage showed the mean infestation level to be less than 1 insect/kg in the cowpea. Moisture content was measured as 9.4% (wet basis) while test of seed germinability indicated that 93% of the seeds were viable.

3.2 Temperature and Relative Humidity Variations in the Storerooms

Temperature and relative humidity variations in both ventilated and non-ventilated storerooms for the twelve-week storage period are presented in Figs. 1 and 2. Minimum and maximum temperatures were 24.0 and 35.5 in the non-ventilated store-room while it was 21.5 and 32.5 in the ventilated room. Even though natural ventilation made it possible for the ventilated storehouse to be cooler, there was no significant difference ($p < 0.05$) between the temperature profiles in the two storehouses. Similarly, minimum and maximum RH were 30.0 and 80.0 in the non-ventilated greenhouse while it was 24.0 and 87.0 in the ventilated storehouse. Even though relative humidity was slightly higher in the ventilated storeroom (Fig. 2), they were not significantly different at $p < 0.05$. The increased air-flow through the ventilated storeroom brought about a degree of cooling.

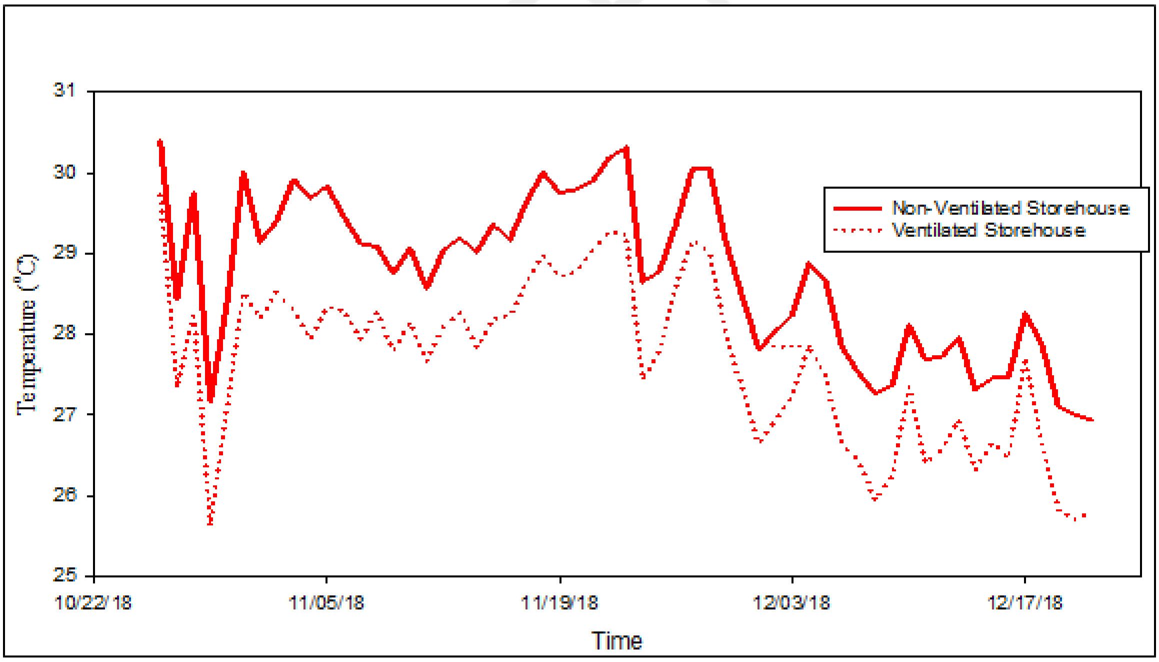

Fig. 1. Mean monthly temperatures within the non-ventilated and ventilated storehouse

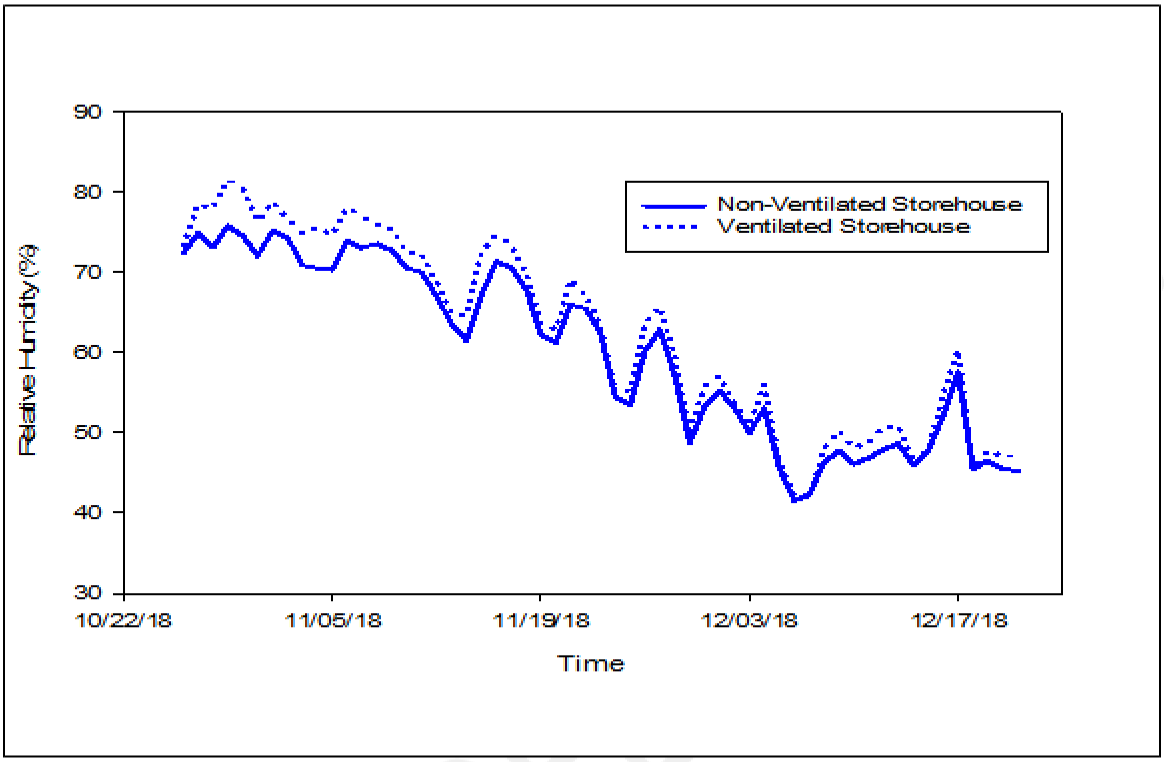

Fig. 2. Mean monthly relative humidity within the non-ventilated and ventilated storehouse

3.2 Effect of Treatments on Insect Population Dynamics (Live and Dead Insects)

The mean monthly live insect count of treated cowpea placed in the ventilated store-room is presented in Table 1. The highest live insect count was observed in the untreated cowpea while the lowest live insect count was observed in VPSO treated cowpea. A significant difference (p<0.05) in insect numbers infesting the treated and control samples after one month of storage. Insect count at the end of two months of storage showed no significant difference between treated samples, but was significantly higher (p<0.05) in the untreated cowpea. A significant difference in insect population was however observed among all the treatments at the end of three months of storage, with the highest live insect count observed in the untreated while the lowest insect count was observed in VPSO. Similar results were provided by [41] who reported that oil obtainable from the neem tree (*Azadirachta indica* A. Juss) resulted in mortality of insects depending on the dosage. The monthly mean insect mortality of treated cowpea grains stored in the ventilated storeroom are presented in Table 2. A significant difference (P < 0.05) was observed among the three treatments used in the first month of storage with VPSO having the highest insect mortality in the first month while the untreated cowpea having the lowest insect mortality. Insect mortality in the second month of storage however showed no significant difference between DE and VPSO.

Insect mortality in the untreated cowpea was lower in the first and second months yet highest in but high in the third month, an observation attributed to die-offs among the insects. Even though insect mortality remained lowest in VPSO, it is an indication that it was the most effective in controlling *Callosobruchus maculates* all through the storage period because it was able to keep insect populations low as evidenced in the live insect counts. This is because the insect reproduction was impeded when compared to DE whose efficacy in retarding oviposition had waned by the third month of storage.

A similar trend was observed in the non-ventilated store-room as the mean monthly live insect count presented in Table 3. No significant difference (p<0.05) in the live insect count among all the treatments at the end of the first month of storage while significant differences were observed among all the treatments after 2 months of storage, with the untreated cowpea having the highest value and VPSO having the lowest value. However, there was no significant difference (p<0.05) between untreated and DE treated cowpea in the third month, and live insect count in VPSO treated cowpea was significantly lower. Similarly, in the non-ventilated storeroom, the monthly mean insect mortality is presented in Table 4. Results showed a significant difference among all the treatments in the first month of storage with VPSO having the highest insect mortality and the untreated cowpea having the least. Insect mortality in the second month showed a significant difference among all treatments with DE having the highest and the untreated cowpea having the lowest. Results also showed no significant difference between untreated and DE treatments in the third month, however the insect mortality was significantly lower in VPSO treated cowpea, similar to observations in the ventilated storeroom.

Table 1. Live Insect population in the ventilated storeroom (insects/kg)

Treatments	Month 1	Month 2	Month 3
Untreated	0.7^{b}±0.34	9.5^{d}±4.93	36.1^{f}±19.51
DE	0.34^{a}±0.26	2.7^{c}±2.26	24.8^{e}±23.33
VPSO	0.2^{a}±0.30	2.3^{c}±1.55	10.8^{d}±5.27

Mean with the different superscript on the same column are significantly different at P < 0.05.

Table 2. Insect mortality in the ventilated storeroom (insects/kg)

Treatments	M1	M2	M3
Untreated	1.1^{a}±0.51	8.3^{b}±4.44	52.3^{e}±35.70
DE	5.8^{b}±3.39	13.8^{c}±4.41	75.5^{e}±39.70
VPSO	12.0^{c}±2.63	12.8^{c}±3.06	19.4^{d}±4.00

Insect mortality in the third month was very high in all the treatments in both ventilated and non-ventilated storerooms when compared to the first and second months. This confirms that DE and VPSO had some effect on the control of cowpea weevil in the first two months of storage, and their potency against cowpea weevil deteriorated during the third month (Figs. 3 and 4). Furthermore, the live insects observed during the third month of storage in both ventilated and non-ventilated storerooms for DE treated cowpea were higher compared to VPSO treated cowpea. This indicates that the potency of DE against cowpea weevil deteriorated faster compared to VPSO, an indication of their comparative effectiveness against cowpea weevil. The lower insect mortality in the third month of storage in VPSO treatment indicates the probable presence of a strong oviposition deterrent in the oil. Mortality on seed treated with oil has been attributed to the toxic component of the oil [42]. This conforms with the finding of [33] who reported that *Vitellaria paradoxa* seed oil is effective in partially or completely preventing oviposition of *Callosobruchus maculatus* (F.) and weevil emergence.

Table 3. Insect population in the non-ventilated storeroom (insects/kg)

Treatments	Month 1	Month 2	Month 3
Untreated	0.3^{a}±0.26	2.9^{c}±1.08	37.0^{f}±19.09
DE	0.2^{a}±0.20	1.3^{c}±0.44	33.1^{f}±30.07
VPSO	0.2^{a}±5.63	0.7^{b}±0.53	8.2^{d}±11.30

Mean with the different superscript on the same column are significantly different at P < 0.05.

Table 4. Effect of treatment on insect mortality in the non-ventilated storeroom (insects/kg)

Treatments	M1	M2	M3
Untreated	1.7^{a}±1.16	8.2^{b}±3.49	76.0^{e}±65.37
DE	7.5^{b}±4.46	17.7^{d}±9.19	72.1^{e}±21.03
VPSO	14.4^{c}±5.80	13.1^{c}±2.52	22.3^{d}±14.01

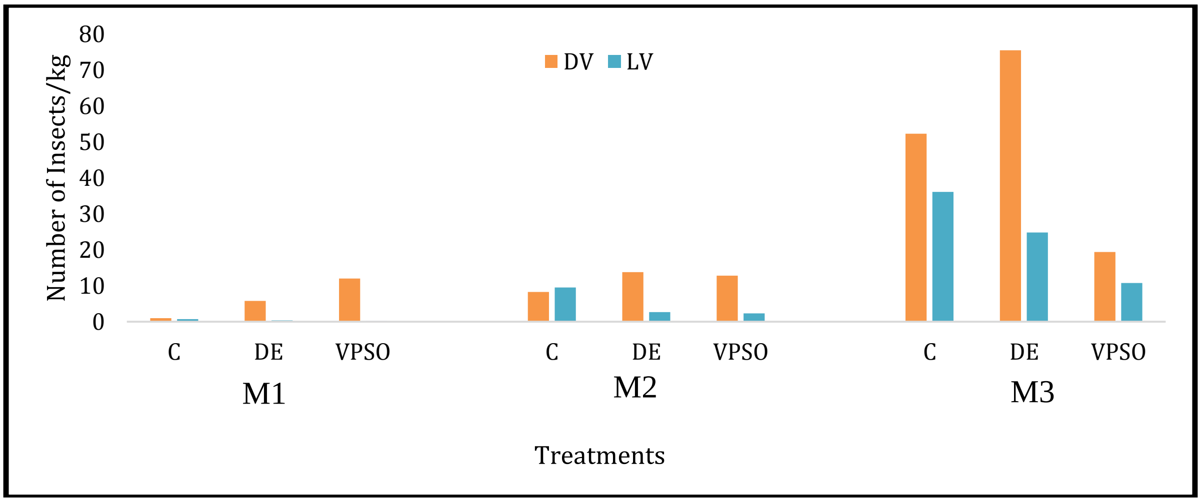

Fig. 3. Comparison of Number of Dead and Live Insects in the Ventilated Storehouse
M = Month, DV = Dead insects in ventilated storehouse, LV = Live insects in ventilated storehouse, C= Control. DE = Diatomeceaous Earth, and VPSO = Vitallaria paradoxa seed

Table 5. Effect of treatments on proximate composition of cowpea grains in the ventilated storeroom

Treatments	Moisture	Ash	Fat	Fibre	Protein	Carbohydrate
Initial	9.4^{a}±0.25	3.4^{a}±0.14	4.4^{b}±0.36	7.3^{c}±0.06	20.4^{a}±0.04	55.1^{a}±0.41
Untreated	10.9^{c}±0.22	3.6^{b}±0.44	2.8^{a}±0.26	2.1^{a}±0.27	25.1^{c}±0.61	55.5^{a}±1.53
DE	10.7^{c}±0.31	3.2^{a}±0.15	3.0^{a}±0.07	2.5^{b}±0.60	25.3^{c}±0.50	55.3^{a}±1.00
VPSO	10.2^{b}±0.24	3.1^{a}±0.15	2.9^{a}±0.26	2.5^{b}±0.30	23.6^{b}±1.69	57.7^{b}±2.01

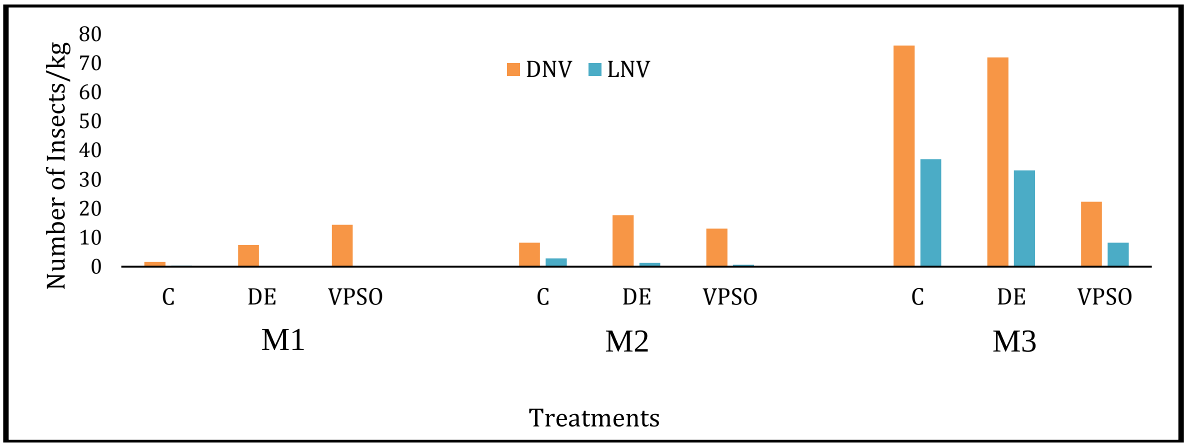

Fig. 4. Comparison of Number of Dead and Live Insects in the Non-Ventilated Storehouse

Table 6. Effect of treatments on proximate composition of cowpea grains in the non-ventilated storeroom

Treatments	Moisture	Ash	Fat	Fibre	Protein	Carbohydrate
Initial	9.4^{a}±0.25	3.4^{a}±0.14	4.4^{b}±0.36	7.3^{c}±0.06	20.4^{a}±0.04	55.1^{a}±0.41
Untreated	9.9^{c}±0.30	3.3^{a}±0.12	3.2^{b}±0.38	2.2^{a}±0.38	24.6^{b}±0.80	56.8^{b}±0.98
DE	9.6^{a,b}±0.19	3.4^{a}±0.13	3.0^{b}±0.09	2.5^{b}±0.29	24.4^{b}±1.22	57.1^{b}±0.95
VPSO	9.7^{b,c}±0.43	3.3^{a}±0.57	2.7^{a}±0.35	2.3^{a}±0.07	25.2^{b}±0.41	56.8^{b}±1.12

3.3 Proximate Composition

The proximate composition of cowpea in the ventilated storeroom after 3 months of storage, compared to the initial values, is presented in Table 5. Results showed a slight increase in cowpea moisture content during the period for all treatments. The increase in moisture content can be associated with insect activity and the hygroscopic nature of grains, given that mean temperature and relative humidity during the storage period were 34.7°C and 62.3% respectively. No significant difference was observed in the moisture content between untreated and DE even though moisture content was lower in VPSO. There was also no significant difference in the ash content between DE and VPSO. Untreated cowpea had the highest ash content after storage. Fat and fibre contents decreased significantly in untreated and all treated grains after storage. Additionally, the fibre content was significantly lower in the untreated cowpea after storage. The initial protein content significantly increased in all treatments after storage, especially for untreated and DE treated cowpea. The results also showed no significant change in the initial carbohydrate content during storage except for the VPSO treatment which increased.

Moreover, the effect of treatments on the proximate composition of cowpea grains after storage in the non-ventilated storeroom is presented in Table 6. As in the ventilated storeroom, results showed a significant increase in cowpea moisture during storage for the untreated and VPSO treated grain. However, no significant change in moisture was observed for the DE treated cowpeas. The results showed no significant change in ash content during storage for all treatments. The initial fat content significantly decreased in all treatments during storage, especially for the VPSO treatment. Similarly, the initial fiber content decreased significantly in all treatments during storage. In contrast, the protein and carbohydrate content levels increased significantly in all treatments during storage.

Both DE and VPSO treated cowpeas had similar nutrient profiles after storage. Cowpea stored in the ventilated storeroom had higher moisture content compared to the non-ventilated storeroom. The lower temperature and higher relative humidity in the ventilated storeroom contributed to this difference because grains are generally hygroscopic. Moreover, high grain moisture increases the likelihood of mold development and other forms of grain deterioration. For instance, [43] stated that typically, an equilibrium relative humidity of 65% or less inside storehouses is desirable in the prevention of mold growth.

Table 7. Effect of treatment on percentage germination in the ventilated storeroom

Treatments	M1	M2	M3
Untreated	62.9^{b}±3.3	68.3^{d}±10.45	64.17^{e}±5.85
DE	75.8^{c}±4.9	72.1^{d}±7.81	62.08^{e}±7.65
VPSO	56.3^{a}±2.1	52.9^{d}±5.79	58.75^{e}±5.18

Table 8. Effect of treatment on germination percentage in the non-ventilated storeroom

Treatments	M1	M2	M3
Untreated	77.9^{b}±5.6	77.1^{d}±6.8	61.7^{e}±7.9
DE	80.4^{c}±4.3	70.8^{c}±4.7	63.3^{e}±8.6
VPSO	66.7^{a}±5.6	65.8^{b}±6.7	62.1^{e}±7.1

DE = Diatomeceaous Earth, and VPSO = Vitallaria paradoxa seed

3.4 Effect of Treatment on Germination Percentage

The monthly mean percentage germination of treated cowpea grains stored in the ventilated store-room are presented in Table 7. The result showed significant differences (P<0.05) among all the treatments in the first month of storage with DE having the highest value and VPSO the lowest. The result also showed that there was no significant difference in the percentage germination among all the treatments in the second and third months of storage. Percentage germination was lower in VPSO treated cowpea throughout the storage period. The low percentage germination observed in VPSO treated cowpea in the first month was similar to the findings of [26] who reported lower viability of maize and cowpea seeds stored using local plant biocides.

Similarly, for the non-ventilated store-room, the monthly mean values for percentage germination of treated cowpea grains are presented in Table 8. The result showed a significant difference in the percentage germination among all the treatments in the first month of storage with DE having the highest and VPSO the lowest. The percentage germination in the second month of storage showed significant differences between all treatments with untreated cowpea having the highest value and VPSO the lowest. Similar to the ventilated storeroom, there was no significant difference between treatments in the third month of storage. The study revealed that germination was significantly higher in DE treated cowpea compared with VPSO treated cowpea in the first and second month of storage. It was also observed that there was also a gradual reduction in germination from the first to the last month of storage in all the treatments in the non-ventilated storeroom. This goes to support the claim by [44] who reported that storing grains for a long period of time cause them to lose the capacity to germinate.

4. CONCLUSION

Diatomaceous earth in its raw form and *Vitellaria paradoxa* seed oil demonstrated potential effectiveness against cowpea weevil at the dosage used only for short term storage of about 1 month and as such requires further processing to increase their potency. Their efficacy deteriorated significantly by the third month, while the potency of DE deteriorated faster compared to VPSO. Furthermore, live insect counts in the non-ventilated store-room were lower as compared to the naturally ventilated storeroom, so no special advantage can be attributed to natural ventilation going by this study.

Diatomaceous earth was most effective for germination under the storage conditions tested, therefore could be selected for treatment of cowpea when seed preservation and germination is considered a major deciding factor. It was also observed that the percentage germination of the stored grain was higher in all treatments in the non-ventilated storeroom.

Diatomaceous earth and *Vitellaria paradoxa* seed oil treated grains had similar nutrient profiles after storage. Cowpea stored in ventilated storeroom had slightly higher moisture content compared to the non-ventilated storeroom. The low temperature and high relative humidity in the ventilated storeroom may have contributed to the higher moisture content of the stored grains compared to the non-ventilated storeroom. Based on the promising potentials of *Vitellaria paradoxa* seed oil as a plant-based pesticide, similar to reports by [42,45], further work is required to improve its potency and establish its efficacy against other storage pests.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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