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Evaluation of Bularafa Raw Diatomaceous Earth in Combination with *Melia azedarach* (L.) Leaf Powder against *Callosobruchus subinnotatus* (Pic.) (Coleoptera: Chrysomelidae) on stored Bambara nut (*Vigna subterranean L. Verdc.*) Seeds

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ABSTRACT
Bambara nut (*Vigna subterranea* L. Verdc.) is an important grain legume and the seeds in storage suffer infestation and damage by *C. subinnotatus*. Laboratory study was conducted to evaluate the efficacy of Bularafa raw diatomaceous earth (BRDE) in combination with *Melia azedarach* leaf powder (MLP) against *C. subinnotatus* on bambara nut seeds. Rearing of the insects and the experiments were conducted in Agricultural Biology Laboratory, Usmanu Danfodiyo University, Sokoto-Nigeria at 29-33°C and a relative humidity of 44-56%. Nine treatment combinations of BRDE (g) + MLP (g): 0.5 + 0.5, 0.5 +1.0, 0.5 +2.0, 1.0 + 0.5, 1.0 +1.0, 1.0 + 2.0, 1.5 +0.5, 1.5 +1.0, 1.5 + 2.0; two grams of Actellic ® dust as standard and a control were evaluated. The treatments applied were separately admixed with 100 g of sterilized seeds in glass jars. Each jar was later infested with thirty, 1-2-days old *C. subinnotatus* of mixed sexes. Each treatment was repeated three times and arranged on a laboratory table using complete randomized design. Results indicate that 100 percent adult mortality was recorded in the highest dose of BRDE + MLP after 96 hours exposure. Treatments significantly ($P < 0.05$) suppressed adult emergence in comparison to the control. The control suffered significantly ($P < 0.05$) higher seed damage (49.5 %) and weight loss (39.7%) thereby recording lower seed germination (36.7%). Adult mortality was significant and negatively correlated with adult emergence, it was also significant and positively correlated with seed viability. The findings indicate that, BRDE + MLP could be a promising alternative against *C. subinnotatus* on bambara nut seeds.

Keywords: Bambara nut seeds, *Callosobruchus subinnotatus,* Melia leaf powders, Bularafa Raw diatomaceous earth

INTRODUCTION
Bambara nut (*Vigna subterranea* L. Verdc.) is an indigenous grain legume grown mainly by subsistence farmers in drier parts of sub-Saharan Africa. In much of Africa, bambara nut is the third most important legume after peanuts and cowpea (Bamishaiye *et al.*, 2011). It is commonly referred to as a "famine crop" or "poor man's crop" (Heller *et al.*, 1997; Bamishaiye *et al.*, 2011). It is a rich source of protein (16-25 %) and its seeds are valued both for their nutritional and economic importance (Coudert, 1982; Berchie *et al.*, 2010). It has become a food security crop and an important source of protein and carbohydrates in the diets of many rural and

urban households, particularly poorer people who cannot afford expensive animal protein (Anchirinah *et al*., 2001; Bamishaiye *et al*., 2011).

Bambara nut seeds are most often infested simultaneously by *Callosobruchus subinnotatus* and *Callosobruchus maculatus*. *C. subinnotatus* (Pic.) (Coleoptera: Chrysomelidae) is restricted to bambara nut in West Africa. These bruchids commence infestation in the field once bambara nuts have been harvested and left to dry (Prevett, 1966; Obeng - Ofori and Dankwah, 2002). Infestation levels in the fields are usually low but, it increases rapidly during storage (Caswell, 1980; Lale and Vidal, 2003). This pest is capable of rendering unprotected seeds unsuitable for planting or consumption (Mbata, 1994). Qualitative losses from this pest may result from the reduced content of valuable ingredients, reduced market quality, reduced storage characteristics, or contamination of the product with parts of pests or toxic products of the pests. It causes damage in terms of seed weight loss, with loss levels reportedly ranging from 30 - 40% in Nigeria (Mbata, 1991; Oparaeke and Bunmi, 2006), to as high as 50% in Ghana (Golob *et al*., 1999).

Synthetic insecticides are widely used to control storage insect pests including *C. subinnotatus*. However, there are problems associated with the use of synthetic insecticides which include the risk to the user, high cost of procurement, effects on non-targets as well as development of pest resistant strains and toxic residue in the food crops. It is therefore imperative to search for safe and environmentally friendly alternative grain protectants such as Bularafa Raw diatomaceous earth (BRDEs) and Botanical powders.

Diatomaceous earth (DEs) is fossilized remains of unicellular algae called diatoms which inhabited marine and fresh water bodies millions of years ago (Kavallieratos *et al*., 2005; Ogreten *et al*., 2025). DEs are promising alternative because they do not require specialized equipment for it application, do not break down rapidly nor do they affect the end use quality. They also have low mammalian toxicity (WHO, 1974; IARC, 1997; Stathers *et al*., 2000 Subramanyam and Roesli, 2000; Athanassiou *et al*., 2003). Large deposits of RDEs have been found in Nigeria (RMRDC, 2009; Nwaubani *et al*., 2014). Several DEs formulations are now registered and commercially available for use as grain protectants in various parts of the world and are generally effective against stored product insects (Stathers *et al*., 2004; Korunic *et al*. 2020; Fayemiro and Abdul, 2024; Wakil *et al*. 2024; Ogreten *et al*., 2025; Wakil *et al*. 2025). Despite these advantages of using diatomaceous earth against insect pests of stored products. There are many drawbacks associated with the use of DEs such as high dosages which lower the grain's bulk density, reduce flowability, cause excessive dustiness, and decrease its overall market value (Fields, 1999; Korunic *et al*., 2020). One of the possible solutions to this problem is the combined use of DEs (including raw diatomaceous earth) with other reduced-risk substances (Athanassiou and Korunic, 2007; Ceruti *et al*. 2005; Stathers, 2003; Abdelgaleil *et al*., 2022; Wakil *et al*., 2025).

Similarly, the use of plant powders has been found to be effective against several stored product insect pests (Boeke, 2002; Nukenine *et al*., 2010) because they are cheap, easy to process, have low mammalian toxicity and biodegradable (Ntonifor *et al*., 2010; Philips and Throne, 2010). *Melia azedarach* (L.) belongs to the family of Meliaceae. It is commonly known as Chinaberry, Persian lilac, pride of India, China tree, Indian lilac, breed tree and Bakain. It is also known as “Icen Kurdi or Kurnar Masar” in Hausa (AL-Rubae, 2009). It is a deciduous tree often grown for its

medicinal uses and for shade or ornament on roadsides (Hammad *et al.*, 2019). It is widely used in traditional folkloric medicine for its pharmaceutical properties (Touzout *et al.*, 2023). It is widely known for its antiviral, antimalarial, antifungal, and antibacterial and insecticidal activities (Kumar *et al.*, 2003; Touzout *et al.*, 2023). Yohannes *et al.* (2014) reported that *M. azedarach* leaf powders tested at 10/100 g caused 100% adults *S. zamias* mortality at 15 days after exposure. Risal *et al.* (2026) have demonstrated the insecticidal potential, grain damage and weight loss activity of *M. azedarach* against *S. zeamais.*

However, there is a paucity of information on the efficacy of BRDE in combination with *Melia azedarach* (L.) leaf powders against *C. subinnotatus*. Therefore, the objective of this study is to evaluate the efficacy of BRDE in combination with Melia leaf powders against *C. subinnotatus* in stored bambara nut seeds.

MATERIALS AND METHODS

Experimental site

The study was conducted in the Agricultural Biology Laboratory, Department of Crop Science, Usmanu Danfodiyo University, Sokoto (UDUS) under ambient laboratory conditions (29-33^{o}C and 49-58% relative humidity). Temperature and relative humidity in the laboratory were recorded using Digital Thermometer and Hygrometer (Model KT-907; Digital Series – China).

Sourcing of bambara nut seeds

A local variety of bambara nut seeds (cv. Ka'aro) used for the study was sourced from farmers in Tambuwal Local Government Area of Sokoto State, Nigeria. It is cream coloured, with large kernel and greyish eye and is the most preferred variety. It was stored in deep freezer at 5^{o}C till they were needed. Before the beginning of the experiments, the seeds were kept under ambient conditions for seven days to equilibrate with the room temperature.

Sourcing of Bularafa Raw diatomaceous earth (BRDE)

Bularafa Raw diatomaceous earth was obtained from Bularafa Town, Gulani Local Government Area, Yobe State - Nigeria. It is a whitish, soft and chalky ore. It was milled into powders using Binatone electric mill (Model BLG-450; China) and sieved using 0.20 mm laboratory test sieve (Endecotts, England). It was kept in an air tight glass jar until needed. The tapped density and pH were analyzed according to methods described by Korunic (1998). Mineral composition was analyzed by X-ray florescence method on Minimate (Panalytical Company, U.K.). BRDE has a tapped density of 314g/l and pH of 9.2. and mineral composition: Bularafa RDE contains 83.04% SiO_2; 5.3% - Al_2O_3; 6.5% - CaO; 3.7%- Fe_2O_3 and less than 1% Na_2O, K_2O, P_2O_5, ZnO, Cr_2O_3, CuO, TiO_2 and MnO. The composition of elements is: Ni 51 ppm; Zr 110 ppm; Sr 76 ppm and Ba 141 ppm. Particle sizes ranged from 1.2 to 13.9 µm.

Collection and Preparation of plant material

Melia azedarach is not common around Sokoto and therefore, it was collected behind the Faculty of Agriculture, University of Maiduguri and identified in the Department of Forestry and Wildlife of the same institution. The plant material was also authenticated at the Botany unit of Usmanu Danfodiyo University, Sokoto. Voucher specimens was prepared and kept in Usmanu Danfodiyo University Herbarium for reference purpose. *Melia azedarach* has UDUH/ANS/0040 as Voucher number. The plant material was dried under shade at room temperature for 7 days and milled into powders using Binatone electric mill (Model BLG-450; China)

and sieved using 0.20 mm laboratory test sieve (Endecotts, England). The powders were preserved in air tight glass jars and stored in a deep freezer at 5°C until needed.

Actellic dust® (pirimiphos – methyl, 2% dust)
Actellic dust® (Pirimiphos – methyl, 2% dust) manufactured by CAP Plc., Nigeria is an organophosphate insecticide purchased from Agrochemical Marketers in Kaduna.

Rearing of *C. subinnotatus*
The adult *C. subinnotatus* were obtained from infested bambara nut seeds sourced from Kara market in Sokoto, Nigeria and the identity of the insects was confirmed at Insect Museum of the Department of Crop Protection, Ahmadu Bello University, Zaria. These were subsequently reared on bambara nut (cv. Ka'aro) which had been sterilized at 80°C for 4 hours in a Gallenkamp hot air oven (England) as recommended by Allotey and Azalekor (2000). Two hundred adult C. *subinnotatus* were placed into 1 litre glass jars containing 500 g of sterilized bambara nut seeds for one week for egg laying after which the parent adult were sieved out. The jars were covered with perforated lids to permit ventilation and prevent escape of adult insects. Adult emergence began 32 days after introduction and the emerging F_1 adult were used for the experiment. Re-culturing was done at regular intervals to ensure availability of insects.

Bioassay
One hundred grams of sterilized bambara nut seeds were weighed using Mettler weighing balance (Mettler PE 200, Switzerland) and placed into 500 ml glass jars, into each jar the different doses of BRDE in combination with Melia leaf powders (MLP) - BRDE (g) + MLP (g): 0.5 +0.5, 0.5 +1.0, 0.5 +2.0, 1.0 + 0.5, 1.0 +1.0, 1.0 + 2.0, 1.5 +0.5, 1.5 +1.0, 1.5 +2.0 were separately added. Actellic® dust at 2.0 g was used as standard and there was an untreated control. Each treatment and the control were replicated three times. After treatment, all the jars, except the untreated control, were vigorously shaken to ensure an effective admixture and the contents were allowed to settle for 30 minutes. Each jar was infested with 30, 1-2 days *C. subinnotatus* adults of mixed sexes. Each jar was then covered with lid, which was cut at the middle but sealed with a mesh (4 cm in diameter) to facilitate ventilation and prevent escape of the insects. The jars were labelled and arranged in a Completely Randomized Design (CRD) on the laboratory table under ambient conditions for Ninety days.

Effect of the treatments on adult mortality and progeny development
Adult mortality was counted in all jars at 24, 48, 72 and 96 hours after treatment by emptying the contents of each jar on a plastic tray, where dead and live insects were counted and recorded. The dead insects were removed while the live ones were returned into their respective jars. Insects were considered dead if appendages did not move when prodded with fine brush (Nukenine *et al.*, 2007).

The live insects were allowed to oviposit for three days after the last mortality count of 96 hours, thereafter, the jars were left undisturbed for adult emergence under the same conditions. Preliminary experiments have shown that adult emergence started 32 days after infestation under ambient conditions. The progeny count started from 32–42 days after treatments for the F_1 adult, and for F_2 generation, adult emergence started from 74–84 days after treatments. All newly emerged adult progeny was sieved out and counted.

Effect of the treatments on seed damage and weight loss

Ninety days after treatment, the seeds in each jar were sieved out to assess the level of damage, by counting the number of seed damaged and undamaged seeds. The percentage seed damaged was calculated according to Ibrahim *et al*. (2012):

$$\%\ \text{seed damaged} = \left[\frac{\text{Number of damaged seeds}}{\text{Total number of seeds}}\right] \times 100$$

Weight loss assessment was determined by taking the difference between initial (before treatment and infestation) and final weight of bambara nut seeds after infestation. The percentage seed weight loss was calculated according to Ibrahim *et al*. (2012):

$$\%\ \text{Weight loss} = \left[\frac{\text{Initial weight - Final weight}}{\text{Initial weight}}\right] \times 100$$

Effect of the treatment on seed viability

After 90 days, the seeds were tested for viability. From each jar, 10 seeds were randomly taken and placed in petri dishes lined with moistened filter paper (Whatman No. 1) and arranged in a Completely Randomized Design (CRD) on the laboratory table under ambient conditions for five days. Each treatment was replicated three times. The number of seeds that germinated after five days were recorded

Data Analysis

Data collected from the study were subjected to one-way analysis of variance (ANOVA) using Statistix version 10.0 software (Statistix, 2013). Corrections for natural mortality in the control treatment was done using Abbott's (1925) formula. Significant difference between treatments means were separated using Tukey – Kramer (HSD) test, at 5% level of significance (Zar, 1999). Correlation analysis was used to determine the association between insect population parameters (adult mortality, progeny production) and seed damage metrics (seed damage, weight loss, germination).

RESULTS

Table 1 showed no significant difference ($P > 0.05$) between some of the different doses of raw diatomaceous earth combined with Melia leaf powders after 24 hours of exposure. However, significant difference among doses was obtained at 48- and 72-hours exposure. Similarly, highest doses of BRDE + MLP resulted in 100% adult mortality after 96 hours exposure which is not significantly different ($P > 0.05$) to the Actellic® dust.

Table 1. Effect of Bularafa raw diatomaceous earth combined with Melia leaf powders on adult *C. subinnotatus* mortality in bambara nut seeds

Treatments	Doses (g/100 g seeds)	Mean (% ± SE) mortality after hours of exposure			
		24	48	72	96
BRDE+MLP	0.5+0.5	25.6±2.2^{e}	48.9±1.1^{d}	62.2±1.1^{c}	74.4±1.1^{e}
BRDE+MLP	0.5+1.0	27.8±1.1^{de}	52.2±2.9^{d}	71.1±4.4^{bc}	76.7±1.9^{de}
BRDE+MLP	0.5+2.0	31.1±1.1^{cde}	53.3±5.8^{d}	65.6±2.9^{bc}	77.8±1.1^{de}
BRDE+MLP	1.0+0.5	33.3±1.9^{cde}	58.9±4.0^{cd}	77.8±2.9^{abc}	82.2±1.1^{cde}
BRDE+MLP	1.0+1.0	33.3±3.8^{cde}	62.2±2.9^{cd}	66.7±5.8^{bc}	83.3±1.9^{cd}
BRDE+MLP	1.0+2.0	36.7±1.9^{cde}	63.3±1.9^{cd}	80.0±1.9^{ab}	87.8±1.1^{bc}
BRDE+MLP	1.5+0.5	40.0±1.9^{bc}	73.3±1.9^{bc}	87.8±2.2^{a}	93.3±1.9^{ab}
BRDE+MLP	1.5+1.0	38.9±2.9^{cd}	78.9±4.0^{ab}	93.3±3.3^{a}	97.8±1.1^{a}
BRDE+MLP	1.5+2.0	51.1±2.9^{ab}	80.0±1.9^{ab}	93.3±1.9^{a}	100.0±0.0^{a}
Actellic dust	2.0	61.1±2.9^{a}	92.2±2.2^{a}	93.3±1.9^{a}	95.6±1.1^{ab}
Control	0.0	5.6±1.1^{f}	6.7±1.1^{e}	7.8±2.9^{d}	7.8±2.9^{f}

Means followed by different superscript within columns are significantly different using Tukey -Kramer HSD test at $P < 0.05$. BRDE = Bularafa Raw Diatomaceous Earth, MLP = Melia Leaf Powder.

Table 2 showed that adult *C. subinnotatus* emergence in treated bambara nut seeds was significantly ($P < 0.05$) lower compared to the control. The highest number of F_1 adult was recorded at 1.0 g + 1.0 g of BRDE + MLP which was not significantly different ($P > 0.05$) from other treatment except, Actellic® dust. Among the treated seeds, the number of F_2 adult emergence were similar, except 1.5 g + 0.5 g of BRDE + MLP which produced the highest number of adult progeny, which was significantly different ($P < 0.05$) from the control, Actellic® dust and higher doses of BRDE + MLP.

Table 2. Effect of Bularafa raw diatomaceous earth combined with Melia leaf powders on adult *C. subinnotatus* emergence in bambara nut seeds

Treatment	Doses (g/10g of seeds)	Mean number of progeny (±SE)	
		No. of F_1 adults	No. of F_2 adults
BRDE+MLP	0.5+0.5	14.0±2.5^{b}	24.7±2.6^{bcd}
BRDE+MLP	0.5+1.0	15.7±0.9^{b}	24.0±1.2^{bcd}
BRDE+MLP	0.5+2.0	13.3±2.4^{b}	22.0±2.1^{bcd}

BRDE+MLP	1.0+0.5	14.0±2.4^{b}	24.0±1.5^{bcd}
BRDE+MLP	1.0+1.0	16.3±2.2^{b}	26.7±1.2^{bc}
BRDE+MLP	1.0+2.0	10.3±0.3^{bc}	18.3±1.2^{bcde}
BRDE+MLP	1.5+0.5	15.0±1.5^{b}	29.0±0.6^{b}
BRDE+MLP	1.5+1.0	11.0±0.6^{bc}	15.7±0.9^{cde}
BRDE+MLP	1.5+2.0	10.0±1.0^{bc}	13.0±1.2^{de}
Actellic dust	2.0	0.7±0.3^{d}	7.3±0.9^{f}
Control	0.0	97.7±7.2^{a}	112.7±6.6^{a}

Means followed by different superscript within columns are significantly different using Tukey - Kramer HSD test at P < 0.05. BRDE = Bularafa Raw Diatomaceous Earth, MLP =Melia Leaf Powders.

Table 3 showed that there was significant difference (P < 0.05) on seed damage. The highest seed damage was recorded in the control (49.5%) and the least was obtained in Actellic dust (4.5%). Weight loss data follows a trend similar to that of seed damage. The highest seed weight loss was recorded in the control (39.7%) while the least was on Actellic dust (4.1%). There was significant difference (P < 0.05) between treated and the control in the germination of bambara nut seeds. Seed germination ranged from 36.7% to 70.0% after 90 days of storage.

Table 3. Effect of Bularafa raw diatomaceous earth combined with Melia leaf powders on seed damage, weight loss and germination of bambara nut seeds after 90 days of storage

Treatments	Doses (g/100 g of seeds)	Mean percentage (% ± SE)		
		Seed damage	Seed weight loss	Seed germination
BRDE+MLP	0.5+0.5	14.1±3.5^{b}	8.4±1.8^{b}	70.0±10.0^{b}
BRDE+MLP	0.5+1.0	14.9±1.7^{b}	8.6±0.7^{b}	63.3±6.7^{b}
BRDE+MLP	0.5+2.0	12.3±1.4^{bc}	7.0±1.1^{b}	63.3±8.8^{b}
BRDE+MLP	1.0+0.5	12.0±0.7^{bc}	6.2±0.6^{b}	60.0±5.8^{b}
BRDE+MLP	1.0+1.0	14.7±0.8^{b}	6.5±0.3^{b}	63.3±3.3^{b}
BRDE+MLP	1.0+2.0	16.3±0.6^{b}	7.4±1.2^{b}	60.0±5.8^{b}
BRDE+MLP	1.5+0.5	14.2±0.9^{b}	7.7±0.5^{b}	66.7±3.3^{b}
BRDE+MLP	1.5+1.0	13.8±0.8^{bc}	7.7±0.6^{b}	70.0±5.8^{b}
BRDE+MLP	1.5+2.0	8.2±0.5^{bc}	4.6±0.7^{b}	70.0±5.8^{b}
Actellic dust	2.0	4.5±0.5^{c}	4.1±0.4^{b}	70.0±10.0^{b}

Control	0.0	49.5±4.3[a]	39.7±3.5[a]	36.7±3.3[a]

Means followed by different superscript within columns are significantly different using Tukey - Kramer HSD test at $P < 0.05$. RDE = Bularafa Raw Diatomaceous Earth, MLP = Melia Leaf Powders.

Correlation matrix between variables: adult mortality, adult emergence, percentage seed damage, seed weight loss and seed viability as affected by raw diatomaceous earth combined with Melia leaf powders in bambara nut seeds against infestation by *C. subinnotatus* are presented in Table 4. It is clear from the results that negative relationship existed between adult mortality (r = -0.9522), seed damage (r = -0.9196), seed weight loss (r = -0.9319). However, seed damage (r = 0.9583), seed weight loss (r = 0.9643) was positively associated with an adult emergence. Seed viability was significant and negatively correlated with adult emergence (r = -0.6386), seed damage (r = -0.6617) and seed weight loss (r = -0.6669).

Table 4. Correlation matrix (Co-efficient value) showing the relationship between different variables on the effect of Bularafa raw diatomaceous earth combined with Melia leaf powders in bambara nut seeds against infestation by *C. subinnotatus*

	Adult mortality	**Number of adult Emergence**	**% Seed damage**	**% Seed weight loss**	**% Seed viability**
Adult mortality	1.000				
Number of adult emergence	-0.9522	1.000			
% Seed damage	-0.9196	0.9583	1.000		
% Seed weight loss	-0.9319	0.9643	0.9394	1.000	
% Seed viability	0.6372	-0.6386	-0.6617	-0.6669	1.000

Significant at (5% level of significance).

DISCUSSION

Adult mortality of *C. subinnotatus* infesting bambara nut seeds treated with BRDE combined with Melia leaf powders showed that the adult mortality ranged from 93.3 to 100.0% when high doses of BRDE were combined with MLP after 96 hours exposure period. It is pertinent to note that Bularafa Raw diatomaceous earth exerts physical mode of action against the insects by restricting their movements in the treated seeds and higher dosages are needed to achieve the desired level of control. The insecticidal activity of *M. azedarach* may be attributed to its phytochemical constituents which may act as anti-alimentary and antifeedant. Therefore, the combination of BRDE and Melia leaf powders enhanced their efficacy and reduced the higher dosages needed. It was observed in this study that adult mortality increases with an increased in the doses and exposure periods.

The findings of the study agree with Stathers (2003) who found that combinations of DE and plant extracts or soil bacteria metabolites formulated as "All Natural" and "Spindeba" and permethrin at application rates of 2 ppm caused a high knockdown of Larger grain borer *Prostephanus truncatus* (Horn) within seven days. Ceruti *et al.* (2005) also reported that DE combined with low dosages of deltamethrin powder proved effective against *S. zeamais* in stored corn. Athanassiou and Korunic (2007) found that DE enhanced with abamectin caused 100% mortality of adults S. *oryzae*, *R. dominica*, *T. castaneum* and *C. ferrugineus* on wheat after 21 days exposure. Similarly, Fayemiro and Abdul (2024) reported that combination of Diatomaceous earth Silico-sec with three plant powders (the dry flower buds of *Eugenia aromatica*, seeds of *Piper guineense*, and leaves of *Nicotiana tabacum*) offered the best protection, exhibiting significantly higher mortality, lower oviposition rates, suppressed F_1 adult emergence, and reduced seed damage compared to sole treatments. Furthermore, Wakil *et al.* (2025) Stated that the combination of DEs with biological agents that have insecticidal properties (e.g., essential oils, plant powders, silica gel, and species/isolates of fungi), were very effective in reducing the quantities used in single-application treatments.

The results showed that BRDE combined with MLP affected the development of adult progeny. It was observed that few F_1 and F_2 adult *C. subinnotatus* emerged from the treated seeds compared with the control. The results demonstrated that the higher doses of the treatment combinations were more toxic and effectively reduced adult emergence. The reduction in adult emergence could either be due to low fecundity, or larval mortality or even reduction in the hatching of the eggs. It could also be as a result of feeding deterrence resulting in the death of the insects or ovicidal action leading to reduced progeny production. The findings of this study are in agreement with the findings of other researchers (Mulatu and Gebremedhin, 2000; Abdelgaleil and Nakatani, 2003; Vayias *et al.*, 2009; Andric´ *et al.*, 2012). Which reported that the combination of DEs with other reduced risks insecticides reduces progeny production in many stored products insect pests. Fayemiro and Abdul (2024) also reported that combination of Diatomaceous earth (Silico-sec) with three plant powders (the dry flower buds of *Eugenia aromatica*, seeds of *Piper guineense*, and leaves of *Nicotiana tabacum*) significantly lower oviposition rates and suppressed *Callosobruchus maculatus* F_1 adult emergence.

It was observed that seed damage and weight loss were higher in the control than the treated seeds. This shows that the treatments with higher number of *C. subinnotatus* suffered more damage and greater weight loss and vice-versa. The least seed damage and weight loss suffered by seeds treated with higher doses of the treatments may be attributed to higher adult mortality and reduced adult emergence. The findings of this study agrees with the work of Demissie *et al.* (2008) which reported that SilicoSec, a mineral industrial filter cake and domestic wood ash reduced percentage grain damage and weight losses caused by *S. zeamais* on maize grains three months post treatment. Nukenine *et al.* (2010) which reported that maize grains treated with SilicoSec, neem seed powder and *Plectranthus glandulosus* (Hook f.) had lower proportion of grain damage and weight loss caused by *S. zeamais* after four months post treatment. Fayemiro and Abdul (2024) also reported that the combination of Diatomaceous earth (Silico-sec) with three plant powders significantly reduced seed damage in cowpea caused by *Callosobruchus maculatus.*

It was observed that the treatment combinations did not adversely affect the viability of bambara nut seeds 90 days after treatments and infestation by *C. subinnotatus*. The highest germination percentage was recorded in the treated seeds and the least in the control. It may be due to various bioactive compounds presence these treatment combinations that blocks feeding activities by the insects and protect the seeds from seed borne fungal infections. The findings of this study agrees with Smiderle and Cicero (1999) who showed that maize seeds treated with diatomaceous earth suffered no deterioration in physiological quality during 12-month storage. The results are also in conformity with Stathers *et al.* (2000) who reported diatomaceous earth products do not have negative effects on seed germination.

Correlation studies among the variables like adult mortality, adult emergence, seed damage, weight loss and viability revealed that there exist an association between the variables. Adult mortality was significant and negatively correlated with adult emergence but positively and significantly correlated with seed viability. This is in agreement with previous studies by Abebe *et al.*(2009); Fekadu *et al.*(2013) which revealed that plant powders and cooking oils show significant effects and inverse relationship on adult mortality and adult emergence of *S. zeamais* and *Sitotroga cerealella* as well as significant positive relationship between adult emergence, seed damage and weight loss.

CONCLUSION

The present study demonstrated that higher dose rates of BRDE in combinations with MLP caused higher adults *C. subinnotatus* mortality on stored Bambara nut seeds. Thus, this work provides insights into the effectiveness of these treatment combinations in the protection of stored Bambara nut seeds against *C. subinnotatus* infestation. These enhanced BRDE + MLP could be a valuable component of IPM- based strategy.

CONFLICTS OF INTREST

The authors declare no conflicts of interest

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