Insecticidal Efficacy of Raw Diatomaceous Earth, and *Jatropha curcas* Seed Powder alone, and in Combination against *Callosobruchus subinnotatus* (Pic.) (Coleoptera: Chrysomelidae) in Stored Bambara Nut (*Vigna subterranea* L. Verdc.) Seeds

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ABSTRACT: Laboratory bioassay were conducted to assess the insecticidal efficacy of raw diatomaceous earth (RDE), *Jatropha curcas* seed powders (JSP) alone and in combination against *Callosobruchus subinnotatus* in stored bambara nut seeds. The study was carried out under ambient laboratory conditions at 30 ± 2 °C and 55 ± 4 % relative humidity using Completely Randomized Design. The seeds were admixed with the RDE, JSP each at three dose rates as unitary (RDE: 0.5, 1.0 and 1.5 g/100 g) and (JSP: 0.5, 1.0 and 2.0 g/100 g) and their binary combination at (0.5+0.5, 1.0+1.0, 1.5+2.0 g/100g). Actellic[®] dust at the rate of 2.0 g/kg and untreated control were used as positive and negative controls, respectively. Each glass jar (500 ml) was later infested with 30, 1-2-days old *C. subinnotatus* of mixed sexes. Adult mortality was assessed from 24 hours to 96 hours after treatment (HAT). F_1 , F_2 adult emergence at 32 and 74 days after treatment (DAT) and percentage seed damage and weight loss were assessed after 90 days. The germination of bambara nut seeds were evaluated at the beginning (before infestation) and after 90 days of treatments and infestation. The results revealed that binary combination of test powders were most effective than either RDE or JSP as unitary applications. The highest dose rates of the binary combination resulted in 100% adult mortality at 72 HAT. Similarly, all treatments demonstrated reduced mean number of F_1 , F_2 adult emergence, seed damage and weight loss compared to the untreated control. Significantly, higher germination percentage was recorded in all treatments before infestation. However, after 90 days of treatments and infestation, the germination capacity of treated seeds decreased, which was significantly different from the untreated control. Bambara nut seeds treated with binary combination gave the best protection against *C. subinnotatus* and thus can be incorporated into integrated stored pest management.

Keywords: Raw diatomaceous earth, *Jatropha curcas* seeds, *Callosobruchus subinnotatus*, Unitary, Binary combination.

INTRODUCTION

Bambara nut (*Vigna subterranea* L. Verdc.) is an indigenous grain legume grown mainly by subsistent farmers in arid parts of sub-Saharan Africa. In much of Africa, bambara nut is the third most important food legume after cowpea

and groundnut (Hillocks *et al.*, 2012; Mkandawire, 2007). Bambara nut is important for smallholders and their households because the seeds are an important source of food, highly nutritious, high in protein (16-25 %) and valued for its economic importance (Heller *et al.*, 1997; Hillocks *et al.*, 2012).

The seeds (shelled nuts) are very susceptible to insect infestation both in the field and store (Obeng-Ofori and Dankwah, 2002).

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Callosobruchus attacks bambara nuts in almost all countries of West Africa (Appleby and Credland, 2001; Haines, 1991). The adults lay their eggs on the pod or seed surface, and the larva then burrows into the seed, developing and feeding on the cotyledons before subsequently emerging as an adult (Haines, 1991; Appleby and Credland, 2001; Haines, 1991). Development of *C. subinnotatus* from egg to adults range from 28 to 35 days depending upon temperature and relative humidity (Haines, 1991; Lale, 2002).

Callosobruchus subinnotatus causes significant qualitative and quantitative losses in stored seeds ranging from 30 to 40 % in Nigeria and 50 % in Ghana (Appleby and Credland, 2001; Golob *et al.*, 1999; Haines, 1991; Oparaeké and Bunmi, 2006).

Broad spectrum synthetic insecticides are often used for protecting stored bambara nuts. However, these insecticides are not readily available to farmers due to high cost of procurement, adulteration, risk to the user, development of resistant pest strains, toxicity to non-target organisms and toxic residues left in the protected seeds (Obeng-Ofori and Dankwah, 2002; Oparaeké and Bunmi, 2006). Therefore, the search for an option that can give satisfactory protection and yet be safe and ecologically friendly becomes imperative. Among promising alternatives are diatomaceous earth and plant-derived insecticides. Diatomaceous earth (DE) has low toxicity to mammals and it can be applied without specialized equipment; it kills insects by absorption of cuticular wax leading to water loss and desiccation (Korunic, 1998). Several DE formulations have been evaluated as grain protectants and many of them are now commercially available (Athanasios *et al.*, 2003; Subramanyam and Roesli, 2000).

Raw diatomaceous Earth (RDE) has been found in Northern Nigeria in large deposits (Nwaubani *et al.*, 2014; Otitodun *et al.*, 2015; RMRDC, 2009). It can be used to control *Rhyzopertha dominica* (F.), *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst.) effectively on stored grains and its efficacy is comparable to many commercial DEs formulations (Kabir *et al.*, 2011, 2013; Nwaubani *et al.*, 2014).

Physic nut, *Jatropha curcas* (Linn.)

[Euphorbiaceae], is a multipurpose shrub

reaching a height of up to 8 m (Keith, 2000). It is a native of tropical America, but now thrives in many parts of the tropics and sub-tropics in Africa Asia (Silva *et al.*, 2012). The kernels of the fruit are pressed to give *Jatropha* oil that has been used for decades as a raw material for subsistent and commercial soap making. Its rural industrial usage includes lubrication, soap and candle making, furniture varnish and dyeing (Tigere *et al.*, 2006). Dried ground seeds, leaf extracts, pericarp powders, seed powders, leaf powders and seed oils of *J. curcas* have been reported to be effective against stored insect pests (Jide-Ojo and Ojo, 2011; Negbenebor *et al.*, 2016; Silva *et al.*, 2012). The main biocidal activities of *J. curcas* is due to the phorbol ester (tetracyclic diterpenoid) (Devappa *et al.*, 2011).

Many researchers have shown the potential of combining DEs with other IPM-compatible control methods (Arthur, 2003; Athanasios, 2006; Athanasios and Steenberg, 2007; Ceruti *et al.*, 2005; Otitodun *et al.*, 2015; Yang *et al.*, 2010). However, there is dearth of information regarding the combination of RDE and *Jatropha* seed powders against *C. subinnotatus* infesting stored bambara nut seeds. Therefore, this study evaluated the efficacy of RDE, JSP alone and in combination against *C. subinnotatus* in stored bambara nut seeds.

MATERIALS AND METHODS

Study Site, Test Materials and Insect Culture

The study was conducted in the Agricultural Biology Laboratory, Department of Crop Science, Usmanu Danfodiyo University, Sokoto (UDUS), Nigeria under ambient conditions ($30 \pm 2^\circ\text{C}$ and $55 \pm 4\%$ relative humidity). Seeds of *J. curcas*, obtained from mature fruits collected from the Teaching and Research farm of UDUS, were dehulled, and the kernels air-dried for 15 days under ambient conditions. Dried kernels (3 kg) were milled using Binatone® electric mill (Model BLG-450) and the powder sieved with 0.2 mm Endecotts sieve before storage in airtight glass jars. RDE obtained as crude, soft and chalky rock from the Department of Geology, University of Maiduguri, Nigeria, was similarly milled, sieved and stored in glass jar. Seeds of

Ka'aro, a variety of bambara nut susceptible to *C. subinnotatus*, were obtained from farmers in Tambuwal Local Government Area, Sokoto State. The synthetic insecticide used, pirimiphos-methyl (Actellic 2%D), was purchased from an agrochemical marketer at Kaduna.

Infested bambara nut seeds purchased from Kara market in Sokoto were sieved and the adult *C. subinnotatus* collected used to start laboratory culture in 1-L glass jars containing 500g of Ka'aro bambara nut seeds which had been disinfested at 60°C for 1 hour in a hot air oven (Gallenkamp®) (Obeng-Ofori and Dankwah, 2002). Each jar was infested with 200 unsexed adults and covered with a lid having wire mesh centre for aeration. After seven days, all insects were removed and the jars were observed for emergence of new adults which were used for the test.

Bioassay

One hundred grams of Bambara nut seeds was weighed into 500 ml glass jar and admixed separately with 0.5, 1.0, 1.5 g of each (RDE, JSP) or their binary combinations at the dose rates of 0.5 + 0.5, 1.0 + 1.0, and 1.5 + 2.0. Actellic 2 % Dust (Pirimiphos-methyl) at 2 g/100 g seeds was used as a standard. Untreated seeds served as control. The jars were shaken manually for five minutes to ensure uniform coating of the seeds with the treatments. The seeds were then infested with 1-2 day-old adults of mixed sex (30 adults per jar), and each jar was covered with a perforated lid lined with wire mesh to prevent escape of the insects and facilitate ventilation. The experiment was set up in a completely randomized design and each treatment was replicated three times. Mortality was assessed at 24, 48, 72 and 96 hours after treatment. Adult insects were considered dead when probed with a blunt probe and there were no movements. The experimental set up was kept undisturbed on the laboratory work bench for F_1 and F_2 progeny emergence at 32 and 74 days after treatment and infestation. After three months, seed damage and weight loss were determined.

Germination tests

Two germination tests were performed. The first

was carried out after treatments with RDE, JSP and their binary combinations without infestation by *C. subinnotatus*. Whereas the second test was performed after 90 days on treated seeds and infestation by *C. subinnotatus*. Twenty seeds were selected randomly from each treatment and placed in glass Petri dishes, labelled and left on a laboratory bench. Each Petri dish was lined with Whatman No 1 filter paper and kept moistened throughout the experiment. Each treatment was replicated three times and arranged in a completely randomized design (CRD). Seeds were considered to have germinated when the radicle emerged from the seed coat. Emerged seedlings were counted and recorded after five days and germination percentage was calculated according to ISTA (1996).

Data Analysis

Data collected were expressed as percentages. Data on adult mortality were first corrected for mortality in the controls using the Abbott's (Abbott, 1925) formula. Data on corrected mortality, seed damage, weight loss assessment and germination were arcsine-transformed. Data on number of progeny were square root $\sqrt{x+0.5}$ transformed. These were then subjected to one analysis of variance (ANOVA) using Statistix 8.0 software. Where significant differences existed, treatment means were separated using Tukey-Kramer HSD test at $p < 0.05$ (Zar, 1999).

RESULTS

Table 1 shows the percentage mortality of adult *C. subinnotatus* in bambara nut seeds treated with RDE, JSP alone and their binary combination. The result showed that, generally, adult mortality increased with increase in the dose rates and exposure time. Raw DE alone and JSP alone as well as their binary combinations caused significant mortality to adult *C. subinnotatus* compared to the untreated controls. The lowest dose rate of RDE alone (0.5g/100 g) resulted in (28.9%) adult mortality 24 hours after treatment (HAT), which was not significantly different ($p > 0.05$) from the mortality due to JSP alone (20.0%) at the same

dose rate. Similarly, their binary combinations caused higher adult mortality ranging from (43.3-53.3%). At 48 HAT, Actellic® 2% dust (92.2%) was the most effective against *C. subinnotatus* when compared with the untreated control (5.6%), which was not significantly different ($p > 0.05$) from some of the treatments. At 72 and 96 HAT, the highest dose rate of the

binary combination (1.5 + 2.0 g/100 g seed) had the highest percentage adult mortality (100%) and the least adult mortality (6.7%) was recorded on the untreated control, which were significantly different ($p < 0.05$) from the rest of the treatments (Table 1).

Table 2 represents the effect of treating bambara nut seeds with raw diatomaceous earth

Table 1: Effect of raw diatomaceous earth, *Jatropha* seed powders (alone and in combination) with percentage mortality of adults *C. subinnotatus* in bambara nut seeds

Treatments	Dose rates (g/100 g seeds)	Mean (% $\pm$ SE) mortality hours after treatments			
		24	48	72	96
RDE	0.5	28.9 $\pm$ 1.1 ^{dc}	57.8 $\pm$ 1.1 ^{cd}	70.0 $\pm$ 1.9 ^{bcd}	70.0 $\pm$ 1.9 ^c
RDE	1.0	32.2 $\pm$ 1.1 ^{cde}	58.9 $\pm$ 2.2 ^{cd}	71.1 $\pm$ 1.1 ^{bcd}	78.9 $\pm$ 1.1 ^{bc}
RDE	1.5	38.9 $\pm$ 2.9 ^{bcd}	60.0 $\pm$ 1.9 ^c	72.2 $\pm$ 1.9 ^{bcd}	81.1 $\pm$ 2.9 ^{bc}
JSP	0.5	20.0 $\pm$ 1.4 ^c	33.3 $\pm$ 3.8 ^d	50.0 $\pm$ 1.9 ^d	68.9 $\pm$ 1.9 ^c
JSP	1.0	31.1 $\pm$ 2.9 ^{cde}	53.3 $\pm$ 1.9 ^{cd}	64.7 $\pm$ 0.4 ^{cd}	72.2 $\pm$ 2.2 ^c
JSP	2.0	34.4 $\pm$ 1.1 ^{bcd}	58.8 $\pm$ 2.9 ^{cd}	66.7 $\pm$ 0.2 ^{cd}	74.4 $\pm$ 1.1 ^c
RDE+JSP	0.5+0.5	43.3 $\pm$ 1.9 ^{bcd}	65.5 $\pm$ 2.2 ^{bc}	83.3 $\pm$ 1.9 ^{abcd}	85.7 $\pm$ 1.1 ^{bc}
RDE+JSP	1.0+1.0	50.0 $\pm$ 1.9 ^{abc}	75.5 $\pm$ 2.2 ^{abc}	84.4 $\pm$ 2.9 ^{abc}	88.9 $\pm$ 1.1 ^{bc}
RDE+JSP	1.5+2.0	53.3 $\pm$ 1.9 ^{ab}	86.7 $\pm$ 1.9 ^{ab}	100.0 $\pm$ 0.0 ^a	100.0 $\pm$ 0.0 ^a
Actellic® 2% dust	2.0	68.9 $\pm$ 0.4 ^a	92.2 $\pm$ 2.2 ^a	96.7 $\pm$ 0.0 ^{ab}	97.8 $\pm$ 1.1 ^{ab}
Untreated control	0.0	5.6 $\pm$ 2.9 ^f	5.6 $\pm$ 2.9 ^e	6.7 $\pm$ 1.9 ^e	6.7 $\pm$ 1.7 ^d

Means followed by different superscript within columns are significantly different using Tukey - Kramer HSD test at $P < 0.05$.

RDE =Raw Diatomaceous Earth, JSP = Jatropha Seed Powder

Table 2: Effect of treating bambara nut seeds with raw diatomaceous earth, *Jatropha* seed powders (alone and in combination) with adult *C. subinnotatus* emergence

Treatments	Dose rates (g/100 g seeds)	Mean number of adult emergence (% $\pm$ SE)	
		F ₁ adult	F ₂ adult
RDE	0.5	18.7 $\pm$ 0.9 ^{bc}	21.0 $\pm$ 1.1 ^{bcd}
RDE	1.0	14.7 $\pm$ 0.3 ^{bcd}	15.7 $\pm$ 1.7 ^{bcd}
RDE	1.5	13.3 $\pm$ 0.9 ^{cd}	14.0 $\pm$ 1.0 ^{cd}
JSP	0.5	22.0 $\pm$ 1.5 ^b	27.3 $\pm$ 2.0 ^b
JSP	1.0	16.3 $\pm$ 0.3 ^{bcd}	25.7 $\pm$ 2.6 ^{bc}
JSP	2.0	15.7 $\pm$ 1.8 ^{bcd}	20.3 $\pm$ 2.9 ^{bcd}
RDE+JSP	0.5+0.5	12.7 $\pm$ 0.9 ^{cd}	19.0 $\pm$ 1.2 ^{bcd}
RDE+JSP	1.0+1.0	11.3 $\pm$ 1.2 ^{cd}	17.3 $\pm$ 1.4 ^{bcd}
RDE+JSP	1.5+2.0	9.7 $\pm$ 1.3 ^d	11.0 $\pm$ 1.2 ^d
Actellic® 2% dust	2.0	1.3 $\pm$ 0.3 ^e	3.0 $\pm$ 0.1 ^e
Untreated control	0.0	97.7 $\pm$ 1.2 ^a	112.7 $\pm$ 1.4 ^a

Means followed by different superscript within columns are significantly different using Tukey - Kramer HSD test at $P < 0.05$.

RDE =Raw Diatomaceous Earth, JSP = Jatropha Seed Powder

and *Jatropha* seed powders (alone and in combination) on the mean number of adult *C. subinnotatus* emergence. Adult emergence in all treatments was significantly lower than the untreated control. The number of emerging F_1 , F_2 adult progeny reduced with increased dose rate of all treatments. The binary combinations

reduced adult progeny emergency more than RDE or JSP applied alone, with RDE+JSP at dose rate of 1.5g+2.0g/100 g being more potent and was significantly different ($p < 0.05$) from Actellic® 2% dust.

The effect of raw diatomaceous earth and, *Jatropha* seed powders (alone and their binary

Table 3: Effect of raw diatomaceous earth, *Jatropha* seed powders alone and in combination on the damage and weight loss caused by *C. subinnotatus* in bambara nut seeds

Treatments	Dose rates (g/100 g seeds)	Mean percentage seed ($\pm$ SE)	
		damage	weight loss
RDE	0.5	25.4 $\pm$ 1.6 ^{bc}	15.8 $\pm$ 0.9 ^b
RDE	1.0	17.1 $\pm$ 1.1 ^{cde}	10.0 $\pm$ 0.7 ^{bc}
RDE	1.5	9.7 $\pm$ 0.6 ^{ef}	6.0 $\pm$ 0.3 ^c
JSP	0.5	21.8 $\pm$ 2.9 ^{bed}	14.0 $\pm$ 2.1 ^b
JSP	1.0	27.1 $\pm$ 0.6 ^b	16.4 $\pm$ 1.1 ^b
JSP	2.0	14.5 $\pm$ 2.0 ^{def}	9.0 $\pm$ 1.5 ^{bc}
RDE+JSP	0.5+0.5	18.2 $\pm$ 2.4 ^{bede}	9.2 $\pm$ 0.8 ^{bc}
RDE+JSP	1.0+1.0	14.5 $\pm$ 1.9 ^{d^{ef}}	5.7 $\pm$ 1.1 ^c
RDE+JSP	1.5+2.0	7.1 $\pm$ 0.9 ^f	5.7 $\pm$ 1.9 ^c
Actellic® 2% dust	2.0	1.7 $\pm$ 0.4 ^g	1.0 $\pm$ 0.2 ^d
Untreated control	0.0	50.9 $\pm$ 1.4 ^a	40.8 $\pm$ 1.2 ^a

Means followed by different superscript within columns are significantly different using Tukey - Kramer HSD test at $P < 0.05$.

RDE =Raw Diatomaceous Earth, JSP = *Jatropha* Seed Powder

Table 4: Germination percentage of bambara nut seeds treated with raw diatomaceous earth, *Jatropha* seed powders alone and in combination and infested with *C. subinnotatus*

Treatments	Dose rates (g/100 g seeds)	Mean germination percentage ($\pm$ SE)	
		Before infestation	90 days after infestation
RDE	0.5	91.7 $\pm$ 1.4 ^a	58.3 $\pm$ 1.7 ^a
RDE	1.0	90.0 $\pm$ 2.9 ^a	60.0 $\pm$ 1.0 ^a
RDE	1.5	90.0 $\pm$ 2.8 ^a	58.3 $\pm$ 1.1 ^a
JSP	0.5	91.7 $\pm$ 1.7 ^a	55.0 $\pm$ 1.8 ^a
JSP	1.0	91.7 $\pm$ 1.0 ^a	56.7 $\pm$ 1.3 ^a
JSP	2.0	91.7 $\pm$ 1.4 ^a	66.7 $\pm$ 1.2 ^a
RDE+JSP	0.5+0.5	90.0 $\pm$ 1.6 ^a	70.0 $\pm$ 1.3 ^a
RDE+JSP	1.0+1.0	93.3 $\pm$ 1.3 ^a	73.3 $\pm$ 1.4 ^a
RDE+JSP	1.5+2.0	91.7 $\pm$ 1.7 ^a	78.3 $\pm$ 1.5 ^a
Actellic® 2% dust	2.0	91.7 $\pm$ 1.6 ^a	65.0 $\pm$ 1.6 ^a
Untreated control	0.0	98.3 $\pm$ 1.8 ^a	18.3 $\pm$ 1.7 ^b

Means followed by different superscript within columns are significantly different using Tukey - Kramer HSD test at $P < 0.05$.

RDE =Raw Diatomaceous Earth, JSP = *Jatropha* Seed Powder

combination) on the damage and weight loss caused by *C. subinnotatus* infestation in bambara nut seeds was presented in Table 3. Application of raw diatomaceous earth, Jatropha seed powders alone and their binary combination prevented the infestation and damage of the bambara nut seeds compared to untreated control that suffered significant ($p < 0.05$) seeds damage and weight loss as a result of infestation and feeding activity of *C. subinnotatus*. The highest percentage seed damage (50.9%) and weight loss (40.8%) was recorded in the untreated control and the lowest seed damage (1.7%) and weight loss (1.0%) was on Actellic® 2% dust.

The results on the germination percentage of bambara nut seeds treated with raw diatomaceous earth, Jatropha seed powders alone and their binary combination and infestation by adults *C. subinnotatus* are presented in Table 4. There was no significant difference ($p > 0.05$) between treatments in the germination percentage before infestation by *C. subinnotatus*. The germination test made before infestation with adults *C. subinnotatus* gave a germination percentage ranging from 90.0 to 98.3% in different treatments (Table 4). The germination percentage varied when bambara nut seeds were infested with *C. subinnotatus*. Thus, the highest germination percentage (78.3%) was recorded in jars treated with the highest dose rates of the binary combination whilst jars containing the untreated control showed the lowest germination percentage (18.3%).

DISCUSSION

There has been some research on the insecticidal activity of raw diatomaceous earth and Jatropha seed powder against insect pests of stored products (Kabir *et al.*, 2011, 2013; Nwaubani *et al.*, 2014; Otitodun *et al.*, 2015; Jide-Ojo and Ojo, 2011; Negbenebor *et al.*, 2016; Silva *et al.*, 2012). However, there is paucity of published information on the use of raw diatomaceous earth in combination with Jatropha seed powder against *C. subinnotatus*. Athanassiou *et al.*, (2009) showed the potential of combining DE with reduced-risk substances.

The results from the study showed that raw diatomaceous earth or Jatropha seed powder alone and their binary combination have insecticidal effects against adult *C. subinnotatus* causing adult mortality between 24 and 96 hours after treatments. However, higher adult mortality was recorded in the binary combination than either treatment alone. Adult mortality increased with increasing dose rates and exposure periods. Thus, 72hour exposure resulted in increased adult mortality.

The mode of action for the increased activity of raw diatomaceous earth plus Jatropha seed powder could be attributed to the presence of different active components in these natural products that synergized each other and enhanced its efficacy. The finding of this study is in agreement with earlier studies which showed that stored grain insect pests including *C. subinnotatus* can be controlled by enhanced DE formulations. For example, Yang *et al.*, (2010) reported that combination of garlic, *Allium sativum* (L.) essential oil with diatomaceous earth (DE) was significantly more effective than either treatment alone against rice weevils, *Sitophilus oryzae* (L.) and red flour beetles, *Tribolium castaneum* (Herbst). Similarly, Michalaki *et al.*, (2006) used *Metarhizium anisopliae* in combination with SilicoSec at two dose rates, 0.2 and 0.5 g/kg of wheat or flour against *Tribolium confusum* and the highest dose rate, increased larval mortality, in comparison with the fungus alone or in combination after seven days of exposure. Also, our findings are consistent with the results reported in other studies (Athanassiou *et al.*, 2003, 2008; Ceruti *et al.*, 2005; Otitodun *et al.*, 2015).

Raw diatomaceous earth or Jatropha seed powder alone and their binary combination significantly reduced progeny production on treated seeds compared to untreated control. This suppression of progeny production was likely caused by inhibited oviposition or toxicity of these treatments to eggs. This is in agreement with Yang *et al.*, (2010) who reported significant reduction in different life stages of *S. oryzae* in grains treated with garlic oil combined with DE. This is also in agreement

with the findings of Ofuya *et al.*, (2015) who found that binary mixture of *Piper guineense* seed powder and DE significantly reduced oviposition and progeny by *C. maculatus* on cowpea.

From the results of this current study, it becomes evident that despite reduced progeny production caused by these treatments, 100% suppression of progeny production was not achieved, which may be attributed to the ability of female beetles to lay their eggs within the seeds and larvae may not be affected until they reach the adult stage. This agrees with Athanassiou (2006) who reported that *Sitophilus oryzae* progenies emerged in stored wheat treated with beta cyfluthrin applied in combination with diatomaceous earth where 100% mortality of exposed adults were recorded.

The germination of bambara nut seeds treated with RDE or JSP alone and their binary combination ranged from 55.0 to 78.3 % after 90 days of treatment and infestation. These results revealed that these treatments did not affect the germination of the bambara nut seeds adversely and this corroborates the results obtained by Obeng-Ofori and Dankwah (2002) who showed that neem seed oils and Actellic® 25 EC did not affect the germination of bambara nut seeds after 90 days of treatments. This also is in agreement with Mariappan *et al.* (2013) who reported that seeds protected with *Jatropha curcas* pelleted with pungam leaf powder and *Pongamia pinnata* seeds pelleted with neem leaf gave high germination percentage due to effective protection from fungal and insect. Biradar Patil *et al.*, (2008) also reported that sweet flag rhizome powder, neem seed kernel powder, neem oil, nimbidine, neem leaf powder and deltamethrin were effective in preventing storage insects and maintaining higher seed quality throughout 10 months of storage.

Relying on the foregoing, it can be safely concluded that binary combination of RDE and JSP are effective in controlling *C. subinnotatus* and could be incorporated into an integrated management of storage pests of bambara nut. Further research is however needed to evaluate

these under field conditions and in traditional storage structures.

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