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Application of botanical powders for the management of stored sorghum insect pests in small-scale farmers' storage structures of Northern Nigeria

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Abstract: *Farmers' storage structures, store rooms, in Pauwa villages of Katsina State, Northern Nigeria were simulated and incorporated with application of leaf powders of Euphorbia balsamifera Aiton, Lawsonia inermis L., Mitracarpus hirtus (L.) DC. and Senna obtusifolia (L.) Irwin and Bemeby, in search for more eco-friendly methods of managing insect pests of stored sorghum. Four most commonly grown sorghum varieties in the study areas, "Farar Kaura" (FK), "Jar Kaura" (JK), "Yar Gidan Daudu" (YGD) and ICSV400 in threshed forms were used for the study. The four varieties (2.50 kg each) were packed in small polypropylene bags, mixed with the leaf powders at the concentration of 5% (w/w) of the plants and kept in small stores of the aforementioned village for 12 weeks. Insect pests recovered after 12 weeks were Sitophilus zeamais, Rhyzopertha dominica, Tribolium castaneum, Cryptolestes ferrugineus and Oryzaephilus surinamensis. There were significant fewer insects pests in treated sorghum than in untreated types ($P < 0.05$). More weight losses were recorded in untreated grains than in those treated with the botanical powders in traditional store rooms. In terms of varieties, grain weight losses were in the order FK > JK > YGD > ICSV400. The botanicals also showed significant ($P < 0.05$) protectant ability against the weevils with their performance in the order E. balsamifera > L. inermis > M. hirtus > S. obtusifolia.*

Keywords: *Botanical powders, Insect pests, Management, Sorghum varieties, Storage structures*

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I. Introduction

Farmers have been evolving a number of traditional practices to avoid huge loss occurring in stored grains due to insect pest infestations [1]. Since agricultural production is seasonal while the demands for agricultural commodities are more evenly spread throughout the year, proper storage of food gains is necessary to prevent spoilage, to keep quality and for monetary reasons [2 and 3].

Most of the sorghum produced in Nigeria is stored at farm/village level by rural farmers to ensure domestic consumption and seed for planting in the next season [3]. Findings of Mahai *et al.* [4] revealed that majority (96%) of farmers of Madagali and Ganye areas of Adamawa State in Nigeria stored their sorghum grains after harvest, and 4% consumed it immediately after harvest. Nigerian farmers store their sorghum in unthreshed or threshed form in thatched "rhumbus", mud "rhumbus", underground pits and small stores [4, 5 and 6].

Safe storage of grains against insect damage is a serious concern [7]. Insect pests has been the major problem of agriculture in the tropics for a long time due to poor post harvest facilities which results in considerable waste of farm produce and hence considerable loss to the economy [5, 8 and 9]. Insect pests damage to stored grains results in reduction of quantity, quality, nutritive and viability of stored crops like maize, sorghum, wheat and rice [10]. Insect pests cause serious damage to sorghum stored in traditional storage structures and market stores of some parts Nigeria [6 and 11].

The knowledge and use of botanicals as grains protectants has been in existence for a long period. A researcger considers botanical method as an indigenous pest management for reducing damage caused by pests [12]. This was supported by reporting that powders of *A. indica*, *Agave sisalana*, *Eucalyptus camaldulensis*, *C. citratus* and *T. minuta* possessed high insecticidal activity against *C. chinensis* [12]. A total adult mortality of *S. zeamais* was recorded in wheat grains treated with *Azadirachta indica* [13]. There is scanty information on the use of botanicals in the control of insect pests of grains stored in farmers' stores [6, 14 and 15]. Therefore, this study was aimed at investigating the effects of leaf powders of *E. balsamifera, L. inermis, M. hirtus* and *S. obtusifolia* on insect pest infestations in sorghum varieties in store rooms.

Some bioactive components of *E. balsamifera* were identified as alkaloids, flavonoids, tannins, saponins, glycosides and terpenoids [16] which suggested its insecticidal properties. Additionally, reported leaf extract from *E. balsamifera* were reported to be repellent against mosquitoes as a scientific proof of the repellence effect of the plant against insects [17].

L. inermis has been found to possess insecticidal properties by some researchers. *L. inermis* was used to control *T. granarium* on wheat grains at the dose of 1, 2, 4 and 6 g/100 g grains and resulted in 100% adult mortality of *T. granarium* 14 days after application at all the three doses [18]. *L. inermis* was found effective in reducing tick infestation on cattle, buffalo and sheep [19]. Further, it was reported that *L. inermis* contained some bioactive compounds of insecticidal actions such as flavonoids, tannins, phenolic compounds, alkaloids, terpenoids and quinines [20].

M. hirtus is an annual herb belonging to the genus *Mitracapus* of the family Rubiaceae and it is generally erect that can be simple or sometimes much branched, and the stems can be 30 – 60 cm tall. Studies were conducted on phytochemical screening of four medicinal plants traditionally used in Nigeria for skin infection, and foung that *M. villosus* (an allied species of *M. hirtus* contains some bioactive components such as tannins, flavonoids, saponins, alkaloids and cardiac glycosides [21]. Presence of these compounds could make the plant to be of insecticidal importance as previously suggested [22].

S. obtusifolia is a common weed of open disturbed areas, arid lowlands and disturbed areas. It is commonly called coffee weed or java bean. *S. obtusifolia* is a common annual plant that grows wild in Northern Nigeria and considered as a serious weed to Agriculturalists in many places [23]. Presence of bioactive compounds such as alkaloids, tannins, saponins, flavonoids, etc suggests the plant's bactericidal, pesticidal or fungicidal property [22].

II. Materials And Methods

2.1 Study area

The study was carried out at Pauwa village with the mean annual rainfall of 600-700 mm and 800-1000 mm respectively. Katsina State is located in the North western Nigeria between latitudes $11^0 08'$N and $13^0 22'$N and longitudes $6^0 52'$E and $9^0 20'$E. with mean temperature and relative humidity of 21.3-34.5^{0}C and 32.5-42.2%, respectively [24]. The work was conducted under conditions of 27 to 33^{0}C and 68 to 83% RH in store rooms.

2.2 The storage structures

Five farmers volunteered their store rooms at Pauwa village for use in this research as in-house stores following the methods of Utono [6]. It was observed that farmers do not keep their farm produce in rhumbus at Pauwa village. The store rooms were made up of mud blocks and plastered/ not plastered with cement. Wooden rafter and zinc sheets served as roofing materials. To improve protection against rodents, a portion of 1.5 m^2 was demarcated using wire cage for storing the grains in each of the selected store rooms. The store rooms were at least 200 m apart.

2.3 The sorghum varieties

Four sorghum varieties namely "Farar Kaura" (FK), "Jar Kaura" (JK), "Yar Gidan Daudu" (YGD) and ICSV400 in threshed forms were used for the study (Plate 1). The first three were purchased from the local farmers, while the last one was purchased from Katsina State Agricultural and Rural Development Authority (KTARDA). The varieties were selected because they are the most cultivated in the study areas, namely, Dallaje and Pauwa villages of Katsina State of northern Nigeria. The varieties were sorted to remove dust, any insect that might be present, broken grains, and other foreign particles using laboratory test sieves with 1, 2 and 4 mm apertures. The screened sorghum varieties were then placed in new sterilized polypropylene bags and disinfested in CO_2 laboratory refrigerator at – 20^{o}C for 7 days and allowed to acclimatize to environmental conditions for 24 hours before taken to the study sites for storage trials.

Plate 1. Threshed sorghum varieties used for the experiments (i) FK); (ii) JK; (iii) YGD; (iv) ICSV400.

2.4 Determination of physical parameters of the sorghum grains

The physical characteristics of the sorghum varieties measured were the grain colour, size (length and width) and hardness.

Grain colour and size: Ten replicates of ten grains from each sorghum variety were sampled to determine length and width of the grains using measuring ruler as described by Usman *et al.* [25].

Moisture content: Moisture content was determined according to Fai *et al*. [26] where 5 g of grains of each of the sorghum varieties were weighed into pre-weighed crucible (W_1) and placed into a drying oven (Model: MINO/100/F, Genlab Limited, Tanhouse Lane, UK) at 105^{o}C for 24 hours. The crucible was removed, cooled in a desiccator and re-weighed. The processes of drying, cooling and re-weighing were repeated until a constant weight (W_2) was obtained. The per cent moisture content was determined as:

$$\%\ \text{Moisture} = (W_2 - W_1)/\text{Weight of sample (5 g)}\ \text{x}\ 100$$

Where: W_1 = Weight (g) of empty crucible; and

W_2 = Constant weight (g) of crucible + sample after drying

Grain hardness: Grain hardness was determined based on the method of Dobie [27]. Three replicates of 10 g of each sorghum variety was weighed and ground in a stainless steel laboratory mortar and pestle. The flour obtained was sieved using 80 µ aperture sieve for 15 seconds in each case. The fractions of the sorghum passing through and retained by the sieve were weighed and recorded as “filtrate” and “residue” respectively. Sorghum grains that produced more filtrate and fewer residues were considered soft. Those that produced less filtrate and more residues were considered hard. Those with equal filtrate and residues were considered moderately hard.

2.5 Preparation of leaf powders

Sufficient amount of fresh leaves of *E. balsamifera*, *L. inermis, M. hirtus* and *S. obtusifolia* was collected from unfarmed area around UMYUK, Nigeria (Plate 2). The leaves were rinsed with distilled water to remove any dust and unwanted particles. They were then shade-dried in Biology Laboratory 3 of UMYUK at room temperature for 14 days. The dried leaves were ground into powder using a laboratory blender (Model 8010ES) and sieved using a laboratory sieve with mesh size of 80 microns to obtain fine powder. The powders were separately kept in black polythene bags to avoid photodegradation, discolouration and moisture uptake [28, 29, 30 and 31].

Plate 2. Plant species selected for the study (i) *E. balsamifera*; (ii) *L. inermis*; (iii) *M. hirtus*; (iv) *S. obtusifolia*.

2.6 Storage trials

Following the methods of Utono [6], five village farmers volunteered their stores at Pauwa village and used for this research as in-house stores. It was observed that farmers of Pauwa village did not transport un-threshed sorghum to stores after harvesting; bags of threshed grains are usually stored in store rooms. Personal interview with the volunteers and a group of some farmers as well as physical observations have shown that only store rooms of varying sizes (depending on quantity of the produce) were used for storing farm produce in this area.

The stores were made up of mud blocks with corrugated iron roofing. Some of the stores were plastered with mud and some not plastered. None of the sample stores had its openings fixed with wire mesh for protection against rodents. Due to absence of protective measures against rodents, the trial was improved by demarcating, a portion of 1.5 m^2 using wire mesh to protect the stored sorghum against rodents in each of the selected store rooms. Wooden pallets were also fixed to place the experimental bags on to prevent damp from the floor reaching the grains (Plate 3).

Plate 3. Storage trials in store rooms (i) Experimental set-up in one of the store rooms; (ii) Bags of sorghum grains kept in a conventional way by a village farmer in Pauwa village.

Four replicates of 2.5 kg each of threshed FK, JK, YGD and ICSV400 sorghum varieties were packed in small polypropylene bags. Each replicate was admixed with 125 g (5% w/w) *E. balsamifera* leaf powder and kept in the 1st store. Similar treatments were made with each leaf powders of *L. inermis*, *M.* hirtus and *S.*

obtusifolia for the 2nd, 3rd and 4th store, respectively. No powder was admixed with the sorghum varieties placed in the 5th store room which served as a control. The environmental conditions under which the experiment was conducted were 29.58 to 31.00°C and 63.75 to 65.67% R.H.

2.7 Determination of insect infestations in sorghum varieties treated with botanical powders

Two hundred and fifty grams (250 g) were randomly sampled monthly (4 weeks) for insect direct count [32]. The grain samples were sieved on white cloth using laboratory test sieves (BS410-1:2000) of different aperture sizes of 80 µm, 1.0 mm and 2.0 mm to remove powders that might have been taken along with the samples, smaller insects and other insects present in the sorghum.

Insects recovered were counted, placed in small sample bottles containing 70% alcohol and labeled accordingly. The recovered insects were then taken to the laboratory for pre-identification using hand lens, stereotype microscope (20X and 40X), identification keys and documented pictures of similar species [33, 34, 35 and 36]. The pre-identified insects were taken to the Department of Crop Protection of the Institute for Agricultural Research, Ahmadu Bello University, Zaria (IAR/ ABU) for confirmation of their identities.

2.8 Determination of weight losses in sorghum varieties treated with botanical powders

At the end of the 12 weeks storage period, threshed and un-threshed samples were sieved using the laboratory test sieves mentioned above. The content collected was transferred into a laboratory sieve of mesh size 2.0 mm for removal of particles smaller than the grains and then to 3.5 mm sieve to isolate grains from other larger particles. Weight loss assessment was carried out as prescribed by Ileke and Oni [13] as follows:

$$\%\,\text{Weight Loss} = (\text{Initial Weight} - \text{Final Weight})/\text{Initial Weight X 100}$$

2.9 Data analysis

The data collected were entered and organized in Microsoft excel spreadsheets and then analyzed using GraphPad Prism (version 7.03) and PAST (version 2.17). They were first tested for normality using Shapiro-Wilk and Jacque-Bera normality tests. One-way ANOVA was employed for grain size and weight losses in each variety. Kruskal-Wallis test was used for analyzing moisture content of the sorghum varieties. Two-way ANOVA was applied for infestation levels of insect pests in the treated sorghum varieties. Significantly different means were separated by Bonferroni's and Tukey's Dunn's multiple comparisons tests for parametric data, while Dunn's multiple comparisons test was applied to non parametric data set.

III. Results

3.1 Physical characteristics of sorghum varieties

It is shown in Table 1 that grain colour varied in the four different varieties. Visual observations proved that the grain colours of FK, JK, YGD and ICSV400 were white, yellow, light-brown and creamy, respectively.

The mean grain length and width of the four varieties differed and indicated that FK had higher mean values followed by JK, YGD and ICSV400 (Table 1). The grain length was highly significantly different among the varieties (ANOVA: $F^{3, 36} = 51.98$, $P < 0.0001$). Bonferroni's multiple comparisons test showed that FK was longer than the other three varieties, though statistically the same as JK. Similarly, there was a highly significant difference in grain width among the varieties (Kruskal-Wallis's statistic: $KW = 24.09$, $P < 0.0001$). Dunn's multiple comparisons test showed that FK, JK and YGD had significantly the same grain width and greater than that of ICSV400.

Table 1. Grain colour, size, moisture level and hardness of the sorghum varieties used for the study

Sorghum Varieties	Colour	Size (mm)		Moisture (%) (Mean ± S. E)	Grain Hardness		
		Length (Mean ± S. E)	Width (Mean ± S. E)		Filtrate (g) (Mean ± S. E)	Residue (g) (Mean ± S. E)	Category
FK	White	5.10 ± 0.10^{a}	4.30 ± 0.08^{a}	10.27 ± 0.07^{ab}	5.81 ± 0.03^{a}	3.09 ± 0.05^{d}	Soft
JK	Yellow	4.85 ± 0.08^{a}	4.20 ± 0.08^{a}	11.00 ± 0.00^{a}	5.51 ± 0.04^{b}	3.58 ± 0.04^{c}	Soft
YGD	Light-brown	4.35 ± 0.13^{b}	4.10 ± 0.07^{a}	10.73 ± 0.07^{ab}	4.38 ± 0.02^{d}	4.38 ± 0.02^{b}	Moderately hard
ICSV400	Cream	3.45 ± 0.09^{c}	3.35 ± 0.11^{b}	10.13 ± 0.07^{b}	4.53 ± 0.06^{c}	4.96 ± 0.03^{a}	Hard

FK = "Farar Kaura"; JK = "Jar Kaura"; YGD = "Yar Gidan Daudu".

Means in the same column followed by different letter superscript are significantly different at $p < 0.05$ by the Bonferroni's and Dunn's Multiple Comparisons Tests.

There was a significant difference in moisture content among the sorghum varieties (Kruskal-Wallis statistic: $KW = 10.20$, $P = 0.0004$). It was in the order JK > FK > YGD > ICSV400, while grain hardness was observed to be in the order: ICSV400 > YGD > JK > FK (Table 1).

3.2 Insect infestations in sorghum varieties treated with botanical powders in store rooms

Five species were recovered from threshed sorghum stored in store rooms of Pauwa village namely: *Sitophilus zeamais* Motsch, *Rhyzopertha dominica* F., *Tribolium castaneum* Herbst, *Cryptolestes ferrugineus* Stephens and *Oryzaephilus surinamensis* L. All the insect species belonged to the order Coleoptera as shown in Table 2.

The number of species in treated grains varied, while all the five species were found in each of the untreated variety (Table 3). Also, the number of species decreased with extension of the storage periods from 4 to 12 WAT. Of the 133.75 insect pests, FK had the highest (44.00), while ICSV400 had the least (22.50). JK and YGD had 34.00 and 33.25, respectively (Fig. 1).

Analysis of variance showed that there was a highly significant interaction between the effects of botanical types and varieties on the number of insects infesting threshed sorghum in store rooms. Also, the difference was highly significant among the treatments (ANOVA: $F^{4, 60} = 305.70$, $P < 0.0001$) and within the varieties as well (ANOVA: $F^{3, 60} = 23.37$, $p < 0.0001$). Post hot test indicated that FK treated with *E. balsamifera* had more infestations than in each of ICSV400 treated with *L. inermis* and *M. hirtus*, respectively. Also, each the treatments were significantly less infested than the untreated sorghum.

FK: There was no *S. zeamais* recorded in all the botanical treatments, while *T. castaneum* had the highest mean number. No *R. dominica* was recovered in *E. balsamifera* and *L. inermis* treatments. *C. ferrugineus* was recorded in *E. balsamifera* only among the treatments, while those with *L. inermis* and *M. hirtus* had no *O. surinamensis* (Fig. 2).

Table 1. Insect pest species recovered in sorghum varieties stored in store rooms of Pauwa village

Scientific/Species Name	English/Common Name	Order	Family	Pest Status
Sitophilus zeamais Motsch.	Maize weevil	Coleoptera	Curculionidae	Primary
Rhyzopertha dominica (F.)	Lesser grain borer	Coleoptera	Bostrichidae	Primary
Tribolium castaneum (Herbst)	Red flour beetle	Coleoptera	Tenebrionidae	Secondary
Cryptolestes ferrugineus (Stephens)	Rusty grain beetle	Coleoptera	Laemophloeidae	Secondary
Oryzaephilus surinamensis (L.)	Saw-toothed grain beetle	Coleoptera	Silvanidae	Secondary

Table 3. Number of insect species infesting threshed sorghum varieties in store rooms

Variety	Mean Number of Species	
	Treated sorghum	Untreated sorghum
FK	4 (1 PP, 3 SP)	5 (2 PP, 3 SP)
JK	1 (1 SP)	5 (2 PP, 3 SP)
YGD	2 (1 PP, 1 SP)	5 (2 PP, 3 SP)
ICSV400	2 (2 SP)	5 (2 PP, 3 SP)

FK = "Farar Kaura"; JK = "Jar Kaura"; YGD = "Yar' Gidan Daudu"; PP = Primary pest; SP = Secondary pest.

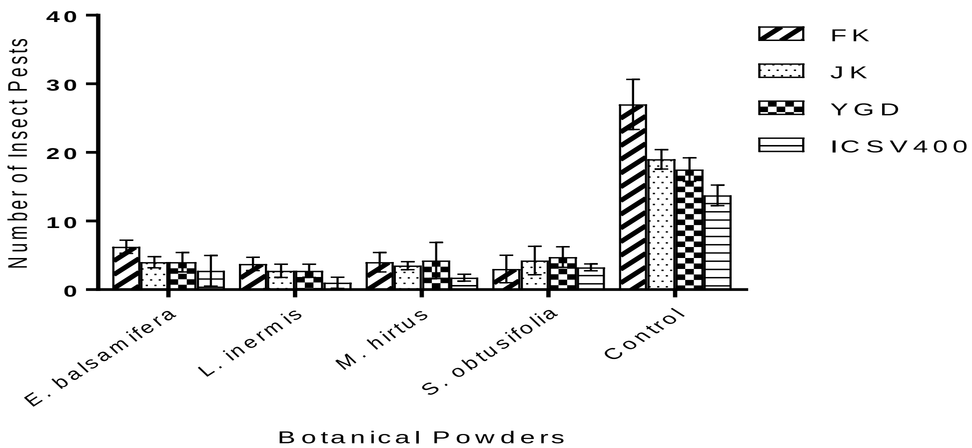

Fig. 1. Mean total number of insect pests in threshed sorghum varieties treated with different botanical powders in store rooms within 12 WAT.

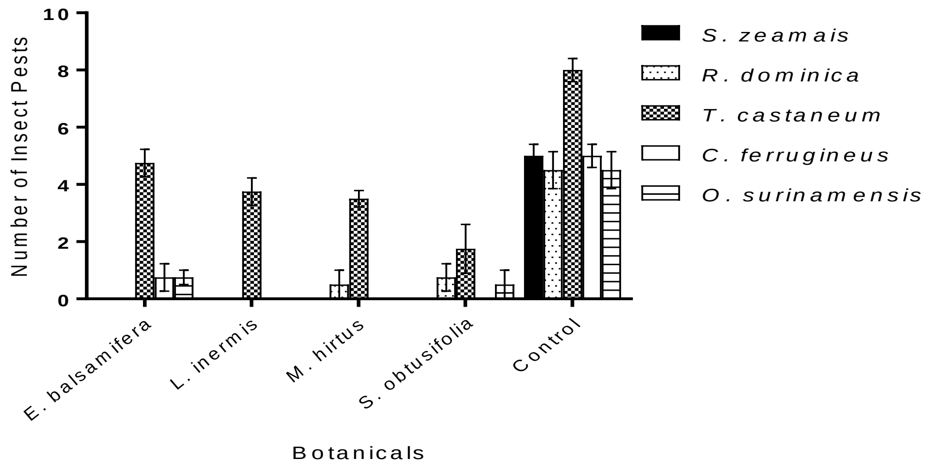

Fig. 2. Mean number of insect pests in threshed FK treated with different botanical powders in store rooms.

The numbers of insect pests in FK were highly significant different (ANOVA: $F^{4,\ 75}$ = 144.80, $P <$ 0.0001) among the botanical types. Similarly, there was a highly significant difference in the infestation levels caused by various insect species (ANOVA: $F^{4,\ 75}$ = 72.43, $P < 0.0001$). Bonferroni's multiple comparisons test indicated that the number of *T. castaneum* was significantly higher than the other insect species in grains treated with each of *E. balsamifera*, *L. inermis* and *M. hirtus*. But in *S. obtusifolia*, the infestations level by all the insect types was statistically the same. Also, *T. castaneum* had significantly higher number than the other four species in untreated samples.

JK: The only insect species recorded in treated JK was *T. castaneum* with its mean number ranging from 3.00 ± 0.71 in *L. inermis* to 4.25 ± 1.03 in *S. obtusifolia*. However, all the five species infested the untreated samples with infestations level in the following order: *T. castaneum* > *S. zeamais* = *C. ferrugineus* > *R. dominica* > *O. surinamensis* (Fig. 3).

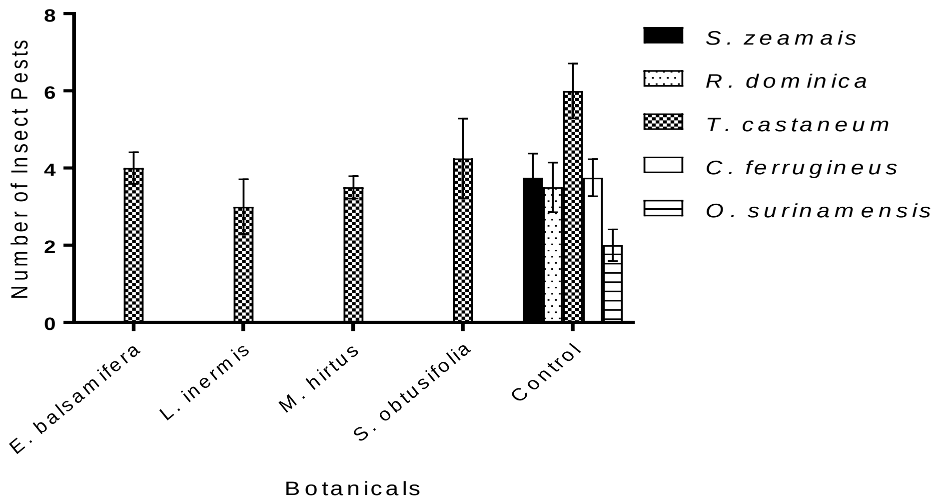

Fig. 3. Mean number of insect pests in threshed JK treated with different botanical powders in store rooms.

There was no significant interaction between the effects of botanical types and insect species on infestations in JK grains in the store rooms (ANOVA: $F^{16,\ 75}$ = 1.331, P = 0.2014). But the numbers of the insects were highly significantly different among the powers (ANOVA: $F^{4,\ 75}$ = 66.92, $P < 0.0001$) and the insect species as well (ANOVA: $F^{4,\ 75}$ = 87.74, $P < 0.0001$). Multiple comparisons test further showed that there was more *T. castaneum* than the other insect species in JK.

YGD: Infestations in YGD varied with insect species as well as the botanical types. No *S. zeamais* and *O. surinamensis* was recorded in all the treated grains, while *R. dominica* and *C. ferrugineus* were found in *M. hirtus* treatments only (Fig. 4). However, *T. castaneum* was observed in all the botanicals and the mean number varied between 2.75 ± 0.48 and 4.75 ± 0.75. The trend of the numbers of insect pests in untreated grains was *T. castaneum* > *C. ferrugineus* > *S. zeamais* > *O. surinamensis* > *R. dominica*.

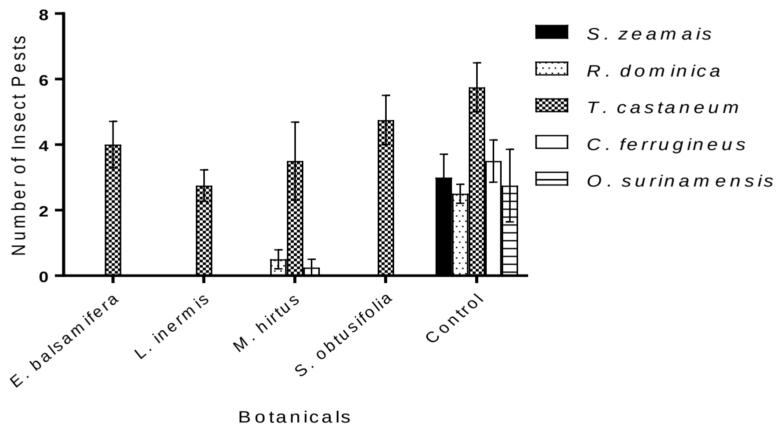

Fig. 4. Mean number of insect pests in threshed YGD treated with different botanical powders in store rooms.

There was no significant interaction between the effects of botanical types and insect species on infestations level in YGD. But the number of insects was highly significantly different among the powers. Similarly, the difference in infestations was highly significant among the insect species. Bonferroni's multiple comparisons test showed that the number of *T. castaneum* was higher than that of the other insects in each of the botanical treatments. Furthermore, the number of *T. castaneum* was statistically the same as that of *C. ferrugineus* and significantly higher than each of *S. zeamais*, *R. dominica* and *O. surinamensis* in untreated YGD.

ICSV400: None of *S. zeamais*, *R. dominica* and *O. surinamensis* was recorded in treated ICSV400, while only 0.50 ± 0.29 *C. ferrugineus* were found in grains with *M. hirtus* (Fig. 5). *T. castaneum* had the highest number in the botanical treatments which ranged from 1.00 ± 0.41 to 3.25 ± 0.25. For the controls, the mean numbers of the five insect species were in the order *T. castaneum* > *C. ferrugineus* > *S. zeamais* > *R. dominica* = *O. surinamensis*.

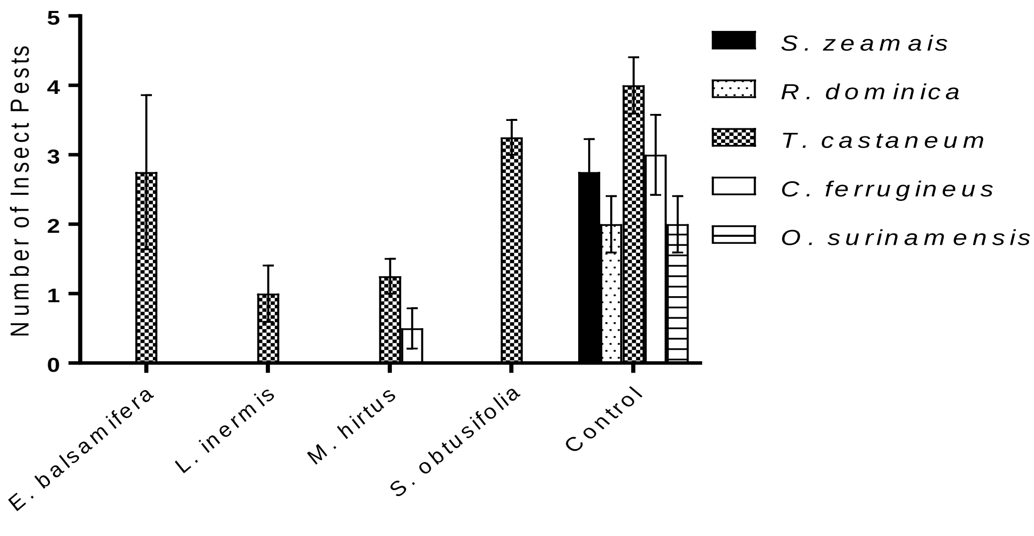

Fig. 5. Mean number of insect pests in threshed ICSV400 treated with different botanical powders in store rooms.

The interaction between the effects of powders and insect pests on infestations in ICSV400 was significant (ANOVA: $F^{16, 75} = 2.30$, $P = 0.0084$). The analysis further indicated that the difference in the number of insects was highly significant among the botanical powders ($F^{4, 75} = 51.56$, $P < 0.0001$) as well as within the insect species (ANOVA: $F^{4, 75} = 35.92$, $P < 0.0001$). Means separation showed that grains treated with *E. balsamifera* and *S. obtusifolia* had significantly higher number of *T. castaneum* than the other four species. In untreated ICSV400, the number of *T. castaneum* was only significantly higher than that of each of *R. dominica* and *O. surinamensis*.

3.3 Weight losses in sorghum varieties treated with botanical powders in store rooms

Weight losses in threshed sorghum varieties treated with botanical powders caused by insect pests in stores of Pauwa village differed after 12 weeks of storage. Among the treated varieties, highest WL (3.20 ± 0.99%) was recorded in FK treated with *S. obtusifolia*. Others are 1.50 ± 0.19% in E. *balsamifera*, 2.90 ± 0.41% in *L. inermis* and 3.10 ± 0.25% in *M. hirtus* (Fig. 6 (i)). The difference in WL of FK was highly significant among the treatments (ANOVA: $F^{4, 15} = 46.41$, $P < 0.0001$). Tukey's multiple comparisons test showed that the difference existed between each of the botanical treatments and untreated grains only.

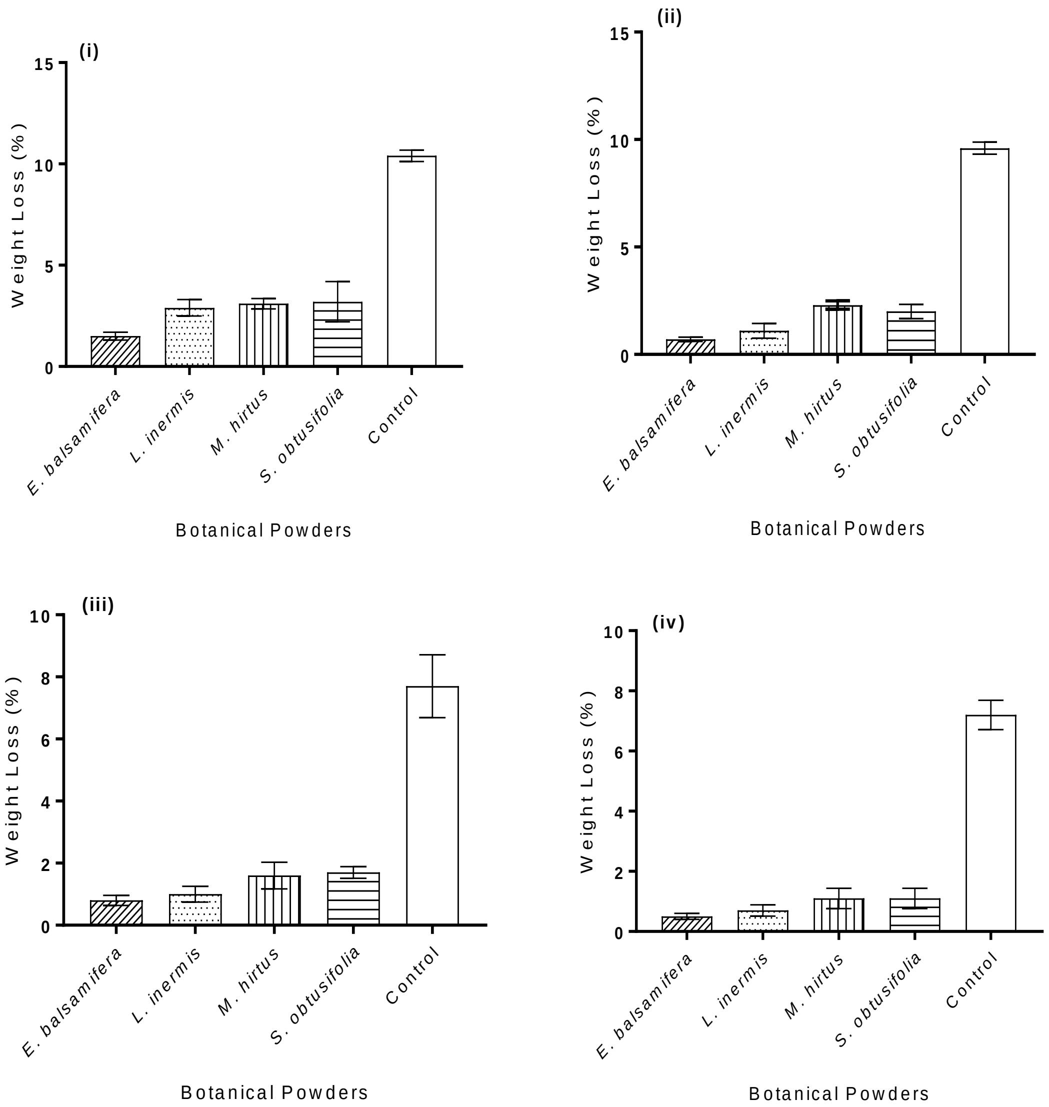

Fig. 6. Percent weight loss in threshed sorghum varieties treated with botanical powders in store rooms (i) FK; (ii) JK; (iii) YGD; (iv) ICSV400.

In treated JK, the WL ranged from 0.70 ± 0.10 to 2.00 ± 0.33%, while it was 9.60 ± 0.29% in the control (Fig. 6 (ii)). There was a significant difference in WL of the variety among the treatments (Kruskal-Wallis statistics: $KW = 15.82$, $P = 0.0033$). Dunn's multiple comparisons test showed that all the botanical treatments had the same WL except that grains with *E. balsamifera* lost less weight than those with *M. hirtus*.

The WL in treated YGD was in the order *S. obtusifolia* > *M. hirtus* > *L. inermis* > *E. balsamifera* (Fig. 6 (iii)). There was a highly significant difference in WL among the treatments (ANOVA: $F^{4, 15} = 31.35$, $P <$

0.0001). Tukey's multiple comparisons test revealed that grains treated with each of the botanicals lost significantly less weight than the control.

The reduction of WL by the botanical powders in ICSV400 was in the following order: *E. balsamifera* > *L. inermis* > *M. hirtus* > *S. obtusifolia* (Fig. 6 (iv)). A significant difference existed in the WL among the treatments (Kruskal-Wallis statistic: $KW = 11.91$, $P = 0.0181$). Although the level of damage varied among the powders, Dunn's multiple comparisons test showed that they were statistically the same and the difference was between each of the treatments and the control only.

Analysis of variance showed that there was no significant interaction between the effects of powders and varieties on WL in threshed sorghum in the store rooms (ANOVA: $F^{12, 60} = 1.284$, $P = 0.2518$). However, simple main effects analysis revealed that the WL was highly significantly different among the powders (ANOVA: $F^{4, 60} = 235.30$, $P < 0.0001$) and within the varieties (ANOVA: $F^{3, 60} = 23.27$, $P < 0.0001$). Means separation by using Bonferroni's test showed that application of *E. balsamifera* to JK, YGD and ICSV400 resulted in lower WL than in FK treated with each of *M. hirtus* and *S. obtusifolia*. Similarly, there was less WL in ICSV400 with *L. inermis* than in each of FK with *M. hirtus* and *S. obtusifolia*. Additionally, the untreated FK was more damaged than the other varieties, but statistically the same as in JK.

IV. Discussion

4.1 Effect of botanical powders on insect infestations in sorghum varieties in traditional store rooms

Sorghum varieties treated with different botanical powders and stored in traditional storage structures showed differences in insect infestations. The store rooms used in this study were the common storage structures used by farmers in Kebbi and Adamawa States of northern Nigeria [4 and 6].

The common insects found infesting sorghum in these structures were *S. zeamais, R. dominica, T. castaneum, C. ferrugineus* and *O. surinamensis* Pauwa village, northern Nigeria. This corroborates previous findings that *S. zeamais*, *R. dominica*, *Cryptolestes* sp., *T. granarium*, *O. surinamensis* and *T. castaneum* were the common insect pests of stored sorghum [37 and 38]. Presence of these insect pests in Fetterita and Gadam Alhamam sorghum varieties stored in some traditional stores of Sudan was reported [39].

The vast number of *R. dominica* in the studied store rooms corresponds to Utono [6] who recorded highest number of the insect in sorghum stored in stores compared to those in maize and millet. Although *S. zeamais* is a serious pest of maize, it is also capable of developing in all other cereal grains. This was also observed by Mailafiya *et al*. [40] that in addition to occurring in maize throughout the savanna zones of northern Nigeria, *Sitophilus* spp. and *R. dominica* attacked sorghum grains in these areas. Appearance of primary pests such *S. zeamais, R. dominica* and *S. cerealella* could be attributed to their ability to fly actively from neighbouring stores and the nature of their mouthparts that are adapted in breaking and feeding on the grains leading to most of the grain damage. This concurs with Rugumamu [41] who observed that damage to maize grains in indigenous storage structures in Morogoro region of Tanzania was mostly caused by the primary pests such as *P. truncatus* and *S. zeamais*.

Existence of secondary pests such as *T. castaneum, C. ferrugineus* and *O. surinamensis* in the stored sorghum grains could be due to availability of broken kernels and flour arising from feeding activities of the primary pests. *T. castaneum* was the most abundant insect pest of sorghum in the store rooms at end of 12 week storage, concurring with Utono [6] that the insect was the most common species with the highest mean number found in sorghum stored in store rooms. This was possible because of the appearance of primary pests within the first 4 weeks but later disappeared probably due to repellent actions of the botanicals. Therefore, the presence of the primary pests within that period might have created conducive conditions for the proliferation of *T. castaneum* which outnumbered weevil numbers in the store rooms, agreeing with Gueye *et al*. [15]. Furthermore, some *T. castaneum* could have visited the experimental grains from the existing bags of sorghum which might have already been infested and kept in the store rooms by the farmers.

The condition of the store rooms had some influence in the insect infestation to the stored sorghum. It was generally observed that the wall of the stores of Pauwa village were observed to be not properly plastered, with cracks allover and some openings which were not rodent proof, thus, allowing free movement of pests.

Grains treated with various botanical powders supported few insects than the untreated, which is in accordance with Gueye *et al.* [15] who reported that *H. spicigera* and *H. suaveolens* incorporated with maize in clay granaries reduced infestations by *T. castaneum* and *S. zeamais*. It was clearly observed that leaf powders of *E. balsamifera*, *L. inermis*, *M. hirtus* and *S. obtusifolia* reduced the number of insect pests in the four sorghum varieties stored in the traditional storage structures. *E. balsamifera* was the found to be the most effective botanical, followed by *L. inermis* and *M. hirtus* and then *S. obtusifolia.*

Varietal difference was found to have influenced infestations level. FK was the most infested variety followed by JK and YGD, while ICSV400 had the lowest infestations level. Similar results were recorded by Beshir [39] that Fetterita appeared to be the most susceptible to infestations (44%) followed by Gadam Alhamam (32%) and Wad Ahmed (20%) and then Tabat (5%).

The local varieties (FK, JK and YGD) used in this study had thinner testae and softer kernels compared to the improved variety (ICSV400). These local varieties supported higher infestations than the improved variety, agreeing with Zakka *et al.* [42] that the resistance exhibited by the improved maize varieties to *S. zeamais* has been attributed to mechanical barriers provided by thick testae and hard grains. However, Lale *et al*. [43] observed that there was no clear effect of physical characteristics (grain hardness, weight, length and width) of maize as an index of determining susceptibility or resistance to *S. zeamais* activity as OBA SUPER1 that had harder seed supported more adult *S. zeamais*. In contrast, this work has found that the physical properties of the sorghum varieties had effect on insect infestations. The larger and softer variety (FK) harboured more insects than the smaller and harder grains.

4.2 Efficiency of botanical powders in reducing damages to sorghum varieties by insect pests

Botanical powders of *E. balsamifera, L. inermis, M. hirtus* and *S. obtusifolia* reduced grain weight losses in different sorghum varieties stored in store rooms. *E. balsamifera* proved to be the most efficacious botanical against insect pests among the powders tested followed by *L. inermis*, *M. hirtus* and *S. obtusifolia*. This is in accordance to some of the laboratory studies of the botanicals against *S. zeamais* [44, 45 and 46].

Little is known on the use of the selected botanicals as protectants against insect pests in the store. However, Suleiman and Suleiman [47] found that botanical powder of *E. balsamifera* reduced cowpea seed weight loss caused by *C. maculatus* to 1.67% compared to 18.33% in the control. This action could be due to repelling property of *E. balsamifera* against some insect pests, such as *S. zeamais* and some insects of medical importance [48] which repelled the insect away from their food sources. *L. inermis* was the second effective botanical powder in reducing grain damage of different sorghum varieties stored in both the storage structures. *S. obtusifolia* was the least effective botanical powder, though significantly ($p < 0.05$) reduced grain damage of sorghum in storage structures compared to the control.

The grain damage was found related to varietal difference, grain forms and storage structures. FK lost more weight than the other varieties in both the storage structures which could be attributed to high infestation levels by the insect pests and their active feeding on the grains. The insects' feeding on grains might be influenced by physical and chemical characteristics of the different varieties as observed by Zakka *et al*. [42] and Lale *et al.* [43].

The insect pests recovered in this study preferred the local varieties especially FK and JK to the improved variety (ICSV400) which could be due to their large size and softness in addition to high moisture level. These factors supported significantly more number of insect pests which might have attributed to its high damage level. High moisture content increases activities of biotic agents, thus increasing loss in storage [49]. The improved variety (ICSV400) had small and hard grains with low moisture level attributing to its least infestation level and hence the least damaged variety. A previous report showed that there was more weight loss in local maize varieties than in improved ones thus indicating a greater preference of such cultivars by *S. zeamais* as suitable substrates for development [42]. Chemical factors such as proximate and mineral contents also play a significant role in grain resistance to insect infestation [43].

The study shows that weight losses in all the threshed sorghum varieties treated with botanical powders of *E. balsamifera*, *L. inermis* and *M. hirtus* in store rooms were within the range of estimated weight loss of 3% to be accepted by farmers [50]. However, Henckes [51] suggested a maximum of 9% weight loss of stored grains to be accepted by farmers. This infers that the botanical powders were efficient to maintain the pests population density below economic threshold (ET) and, hence, preventing them from reaching EIL. Therefore, the botanicals provided protection to sorghum against storage insect pests in traditional structures which could be accepted by farmers.

V. Conclusion

It is evident from this research that the botanical powders were effective in reducing insect pest infestations as well as grain damage of different sorghum varieties in traditional store rooms. It is therefore concluded that the weight losses caused to the treated sorghum varieties in the store rooms were highly reduced inferring that the botanicals were good sorghum protectants against insect pests. Based on the findings of this study ICSV400 could be stored for more than six months storage even if it is not treated with any insecticide because its untreated grains supported a few infestations and reduced weight losses compared to the FK, JK and YGD. Adopting these strategies in the protection of sorghum against insect pest infestations during storage could contribute towards enhancing food security as well as solving cases of malnutrition especially in rural areas where most of the grains are produced.

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