Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
www.entomoljournal.com
JEZS 2021; 9(4): 40-47

Received: 16-05-2021
Accepted: 18-06-2021

Vandi Tigamba
Department of Biological Sciences, Faculty of Science, University of Ngaoundere P.O. Box 454 Ngaoundere, Cameroon

Elias Nchiwan Nukenine
Department of Biological Sciences, Faculty of Science, University of Ngaoundere P.O. Box 454 Ngaoundere, Cameroon

Corresponding Author:
Vandi Tigamba
Department of Biological Sciences, Faculty of Science, University of Ngaoundere P.O. Box 454 Ngaoundere, Cameroon

Insecticidal effects of *Balanites aegyptiaca* and *Lophira lanceolata* seed powders on *Sitophilus zeamais* (Coleoptera: Curculionidae) in stored maize grains

Vandi Tigamba and Elias Nchiwan Nukenine

Abstract
The efficacy of the pulverised seeds of *Balanites aegyptiaca* and *Lophira lanceolata* admixed with maize grains at the rates 0, 5, 10, 20 and 40 g/kg against *Sitophilus zeamais* was determined. The positive control, *Azadirachta indica* seed powder was applied at the unique rate of 5 g/kg. *S. zeamais* mortality was recorded 1-, 3-, 7- and 14-days post infestation, followed by the determination of F_1 progeny production and grain damage. Antifeedant activity of the powders was also assessed. At the content of 5 g/kg, powders of *A. indica*, *B. aegyptiaca* and *L. lanceolata* caused 70.00%, 26.25% and 25.00% mortality to *S. zeamais*, respectively, within 14 days of exposure. *B. aegyptiaca* and *L. lanceolata* caused maximum mortality of respectively 91.25% and 87.50% to the insect at the highest tested content of 40 g/kg, 14-days post treatment. The lowest tested content 5 g/kg of the powders from *B. aegyptiaca* (86.97%) and *L. lanceolata* (79.8%) highly suppressed progeny production, which was comparable to that of *A. indica* (92.20% and 86.11%, respectively), although the test powders almost completely inhibited progeny emergence, at 40 g/kg. The powders also greatly reduced grain damage and weevil feeding activity with a somewhat similar magnitude. Based on our results, seed powders of *B. aegyptiaca* and *L. lanceolata* are sufficiently potent to be considered as alternatives to synthetic insecticides for the protection of stored maize grains against *S. zeamais* infestation. However, safety issues need to be analysed before promoting the two botanical powders as insecticides.

Keywords: plant powders, *Sitophilus zeamais*, mortality, F_1 progeny, damage, antifeedancy

Introduction
The maize plant (*Zea mays*) is an important staple food crop which is grown mainly for human and livestock consumption [31]. In Africa, and especially in the tropics, grains are produced mainly during the short rainy season, and thus storage is inevitable. Maize storage is a common practice in Cameroon [45, 46]. Unfortunately, stored maize is highly devasted by insect pests and other biotic constrains [34, 22, 43], making the protection of stored grains an absolute necessity. This assures food security, fights against hunger and guarantees the availability of seeds for planting [24, 29].

In the tropics, favorable climatic conditions and poorly designed storage structures accelerate the damage of stored grains [34, 44]. According to Guèye *et al*. [22], maize weevil *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) is able to attack grains before and after harvest and could cause up to 40% grain losses in traditional granaries. Moreover, the weevil has been reported to cause up to 80% grain damage in Africa during storage [34].

Synthetic insecticides are the most widely used in controlling insect pest populations. Apart from being very effective, they have high persistence. Unfortunately, peasant farmers lack good technical knowledge of their application; there is also pest resurgence, development of resistance, environmental pollution, increasing cost of application, residues in food and effects on non-target organisms such as parasitoids and predators [19, 37].

The need to find readily available, affordable, less poisonous and environmentally friendly materials that effectively protect stored products, is an interesting measure towards provision of alternative control strategies. Plant derived substances called botanicals come in handy [24, 32, 33]. These could be applied as powders, solvent extracts, ash, essential oils or as entire unmodified plants. Plant powders, which generally do not modify the water content, colour and taste of stored grains have been shown to be very effective against stored product

insects [19, 20, 26]. *Lophira lanceolata* Van Tiegh. Ex. Keay (Ochnaceae) is a tall tree and grows in woody Sudano-Guinean savannah of the tropics. *Balanites aegyptiaca* (L.) Delile (Simarubaceae) is a species of tropical flora for which the spece *aegyptiaca* is adapted to Sahelian climate [39]. They are perennial plants, which are commonly used in traditional medicine and their oils are edible.

Acetone extract of the leaf powder of *B. aegyptiaca* suppressed the hormonal and biochemical process of *Callosobrochus maculatus* Fabr. (Coleoptera: Bruchidae) [42], *Culex quinquefasciatus* L. (Diptera: Culicidae) [1], *Trogoderma granarium* Everts. (Coleoptera: Dermestidae) [27], *Aspergillius* Micheli (Eurotiales: Trichocomaceae) [11] and *Lucilia sericata* Meigen (Diptera: Calliphoridae) [28]. The use of *B. aegyptiaca* as a source of food and medicine by peasants in Africa was reported [40]. *B. aegyptiaca* was reported to be effective against human cancer cells *in vitro* [3]. *L. lanceolata* is used to cure liver infections in Togo and female infertility and cough, diseases of the skin and stomach ache in Nigeria [14]. Oral administration of the aqueous stem bark extract of *L. lanceolata* up to 5000 mg/kg caused neither death nor adverse effects on rats, but resulted in body weight gain, increase in total white blood cells and haemoglobin counts [13]. To the best of our knowledge, there are no published data on the activity of *L. lanceolata* on insect pests, including stored products insects like *S. zeamais*. Although the vegetable oil of *B. aegyptiaca* seeds was tested on *C. maculatus* [37], we did not find any information concerning the activity of the seed powder on insect pests.

This study investigated the effect of the pulverised seeds of *L. lanceolata* and *B. aegyptiaca* on *S. zeamais* mortality, F_1 progeny production, feeding activity and grain damage.

Materials and Methods

Origin of maize seeds

Maize seeds of the variety Shaba were obtained from a farm in Rhumzou village, Mokolo Division, Far North Region of Cameroon in December 2017. In the laboratory, the seeds were sorted, whole grains sealed in polythene bags and disinfested by keeping in a freezer at -18 ± 1 °C for two weeks. They were next exposed for at least two weeks on laboratory shelves under ambient conditions before bioassays. The moisture content of the seeds was 11.25%, determined by the method of AFNOR [5].

Insect rearing

Parent insects were collected from infested maize at the Dang Market in the Ngaoundere III district of the Vina Division in the Adamawa Region of Cameroon. They were reared on 200 g of maize seeds in 2 L transparent plastic cups. Twenty insects of mixed sex were allowed to lay eggs on grains for two weeks. The plastic cups were covered with fine mesh cloth fastened with rubber bands to prevent the contamination and escape of insects. The parental stocks were sieved out and maize seeds containing eggs were left undisturbed until emergence of new adults. Only the subsequent F_1 progeny of *S. zeamais* that emerged from the cultures and aged 7-14 days were used in biological tests. The experiment was conducted under fluctuating laboratory conditions (Temp. = 25.15 ± 0.89 °C and r.h. = 61.72 ± 3.47%).

Plant materials

Ripe fruits of *L. lanceolata* were harvested in March 2016 around the Bini - Lake (latitude 7°24'.885''N, longitude 13°32'.811'' and altitude 1095 masl at about 6 km west of the University of Ngaoundere in the Vina division, Adamawa Region, Cameroon. The fruits were sun-dried and manually decorticated to obtain seeds. For *B. aegyptiaca*, the already decorticated and dried seeds were bought from the local market in Maroua I latitude 10°35'.27'' N, longitude 14°18'57'' E and altitude 508 masl, Diamaré Division, Far North Region, Cameroon in April 2016. Powders of *L. lanceolata* and *B. aegyptiaca* were obtained by crushing the seeds with the rotor manual machine (Victoria grain mill High hopper 600009, Mecanicos Unidos, Colombia), until the particles passed through 0.5 mm mesh sieve (Debyer, France) and put in glass jars before storing in a refrigerator at 4 °C, until needed for bioassay.

Assessment of adult mortality

To evalute the mortality of *S. zeamais*, 50 g of maize seeds were introduced in a 500 mL glass jar. Then 0, 5, 10, 20 and 40 g/kg of *L. lanceolata* or *B. aegyptiaca* seed powders were added into each glass jar containing the seeds. Positive control was treated with neem seed powder (5 g/kg) while the negative control received nothing. Jars were manually shaken for 2 minutes to allow uniform coating of the seeds with the powders. Twenty adult *S. zeamais* aged between 7 and 14 days and of mixed sex were introduced into each glass jar containing treated or untreated maize seeds and then covered with nylon mesh, and sealed with rubber bands. Treatments were arranged in a completely randomized design with four replications each. Adult mortality was assessed 1-, 3-, 7- and 14-days post infestation [31]. Insects were considered dead when no leg or antennal movements were observed when touched with entomological forceps.

F_1 progeny production

After the 14th day mortality count, all adult insects plus botanical powder were removed, while seeds were left inside the jars. The jars were left on laboratory shelves for the assement of F_1 progeny production. The number of emerging adults of *S. zeamais* was counted and recorded weekly starting from the 5th week after treatment and for a period of 5 weeks, to prevent generation overlap [30, 33].

Assessment of grains damage

After the counting of F_1 progeny, the maize grains were left inside the jars in the laboratory for a period six months from the date of treatment. At the end of this period, the number of damaged grains (grains with holes) were sorted and recorded and then both the damaged and undamaged grains were weighed. The percentage weight loss (PWL) was determined using the FAO method [15]:

$$PWL = \frac{(Ua * N) - (U + D)}{Ua * N} * 100$$

U: weight of undamaged fraction in the sample;
Ua: weight of undamaged grains;
D: weight of damaged grains;
N: total number of grains in the sample.

Evaluation of the antifeedant activity

To perform this test, 0, 5, 10, 20 and 40 g/kg of *B. aegyptiaca* or *L. lanceolata* seed powders were separately introduced in glass jars containing 50 g of maize seeds. Jars were manually shaken for 2 minutes to allow uniform coating of seeds with

the powders. The positive control was treated with neem seed powder (5 g/kg), while the negative control received nothing. Twenty *S. zeamais* adults of mixed sex, aged between 7 and 14 days were introduced into each glass jar containing treated or untreated maize seeds and then covered with nylon mesh sealed with rubber bands. Jars were kept on laboratory shelves for 7 weeks after which the number of perforated or non-perforated grains were recorded [30]. All treatments had four repetitions arranged in a complete randomized design under ambient laboratory conditions. The perforation index due to the weevils (WPI) was calculated following the method used by Fatope *et al.* [16]:

$$WPI = \frac{\text{percentage of maize grains perforated in the treated}}{\text{percentage of grains perforated in the untreated}} * 100$$

If the:
WPI > 50: the product negatively protects grains against weevils;
WPI < 50: the product positively protects grains against weevils.

Phytochemical screening of the seeds powder of *L. lanceolata* and *B. aegyptiaca*
In order to identify the constituents of these powders, methods discribed by Edeoga *et al.* [10]; Tiwari *et al.* [41] and Koffi *et al.* [21] were adopted:

Alkaloids: about 0.5 g of the dried powdered sample was boiled in 20 mL of water in a test tube. After filtration, a few drops of 0.1% Ferric chloride was added and observed for a browrish green or blue-black colouration indicating the presence of alkaloids [10, 21].

Flavonoids: 0.5 g of each plant extract was dissolved in dilute $NaOH_{(aq)}$ and $HCl_{(aq)}$ was added. A yellow solution formed indicated the presence of flavonoids.

Tannins: 0.5 g of the dried powdered samples was boiled in 20 mL of water in a test tube and then filtered. A few drops of 0.1% ferric chloride was added and observed for a browrish green or blue-black colouration [10, 21].

Saponins: 2 g of the powdered sample were boiled in 20 ml of distilled water. 10 mL of the filtrate was mixed with 5 ml of distilled water and shaken vigorously for a stable persistent froth. The frothing was mixed with 3 drops of olive oil and shaken vigorously, then observed for the formation of emulsion [10, 21].

Anthraquinones: 0.5 g of each powder was boiled with 10% HCl for a few minutes in water. It was filtered and allowed to cool. Then 10% of $CHCl_3$ was added and few drops of $NH_{3(aq)}$ were added and heat. A reddish-pink color formed indicated the presence of anthraquinones [10, 21].

Reducing sugar: The powder was mixed with distilled water and filtrated. Then boiled with drops of Fehling's solution A and B for 5 minutes. An orange-red precipitate formed explained the presence of reducing sugars [10, 21].

Polyphenols: 2 mL of each powder's aqueous solution was mixed with ferric chloride ($FeCl_3$), then a drop of alcohol was added with 2% ferric chloride. The formation of a blackish-blue or green more or less dark color indicated the presence of polyphenols [10, 21].

Triterpenes and Sterols: Liebermann reagent was used. 5 mL of each solution of the plant powder was evaporated to dryness. The residue was dissolved in 1 mL of hot acetic anhydride. Then 0.5 mL of concentrated sulfuric acid was added down the sides of a test tube to form a layer underneath. The appearance of a purple and purple ring, turning to blue then green, indicates a positive reaction [10, 21].

Carbohydrates: Two drops of Molisch reagent was added to the solution of each powder. Then 2 mL of concentrated sulphuric acid was added by the side of the test tube. The formation of reddish violet ring at the junction of the liquids indicated the presence of carbohydrates [41].

Free quinones: To highlight the free or combined quinones, the Borntraegen reagent was used. 2 mL solution of each powder were evaporated to dryness. The residue has been crushed in 5 ml of hydrochloric acid 1/5. It is then carried to water bath for 30 min and cooled afterwards. Then extracted with 20 mL of chloroform. Diluted Ammonia (0.5 mL) was added to the chloroform solution. A red or purple color appeared as sign of the presence of quinones [10, 21].

Coumarins: 1 g of powder was moistened with a few drops of distilled water and transferred to a water bath at 100 °C. The tube was covered with a wet filter paper soaked with a dilute solution of 10% NaOH. The filter paper was examined under the ultraviolet slide and a yellow fluorescence was observe as a sign of the presence of coumarines [41].

Data analysis
Control mortality was corrected using the Abbott formula [2]. Percentage of cumulative corrected mortality, antifeedant effects, percentage of F_1 progeny production and percentage of damaged grains were Arcsine [(square root(x/100)] transformed to homogenize the error variance and the number of F_1 progeny was $\log_{10}(x+1)$ transformed for normality, before subjecting to the analysis of variance (ANOVA) procedure using SPSS version 20. Mean separation was performed with Tukey test at the 5% significance level.

Results
Adult mortality
The results of the adult mortality tests showed that pulverized powders from the seeds of *L. laceolata* and *B. aegyptiaca* caused significant (P<0.0001) mortality to *S. zeamais* 7- and 14-days post treatment (Table 1). Maximum mortality recorded for *L. laceolata* and *B. aegyptiaca* were 87.50% and 91.25%, respectively, which occurred with the highest tested powder content of 40 g/kg, 14 days after exposure. *S. zeamais* was more sensitive to the positive control, *A. indica* seed powder than the two test powders. At the powder content of 5%, *A. indica*, *L. lanceolata* and *B. aegyptiaca* seed powders caused 70.00%, 25.00% and 26.25% mortality to *S. zeamais*. However, higher contents (>10%) of the powders of *L. lanceolata* and *B. aegyptiaca* generally achived similar mortality to the 5% powder content of *A. indica*.

Table 1: Cumulative mortality (mean ± standard error) of *Sitophilus zeamais* exposed to the seed powders of *Balanites aegyptiaca* and *Lophira lanceolate*

Doses (g/kg)	Exposure period (days after exposure)			
	1	3	7	14
		Lophira lanceolata		
0	00 ± 00^{a}	00 ± 00^{a}	00 ± 00^{a}	00 ± 00^{a}
5	00 ± 00^{a}	0.00 ± 0.00^{a}	13.75± 6.88^{ab}	25.00 ± 4.56^{ab}
10	00 ± 00^{a}	1.25 ± 1.25^{a}	27.50 ± 8.78^{abc}	37.50 ± 4.33^{b}
20	00 ± 00^{a}	2.50 ± 1.44^{a}	43.75 ± 10.68^{bc}	55.00 ± 11.73^{bc}
40	00 ± 00^{a}	5.00 ± 2.88^{a}	65.00 ± 13.38^{c}	87.50 ± 10.90^{d}
A. indica (5 g/kg)	00 ± 00^{a}	6.25 ± 3.75^{a}	51.25 ± 4.27^{bc}	70.00 ± 3.53^{cd}
$F_{(4,15)}$		1.58^{ns}	8.15 ***	19.49***
		Balanites aegyptiaca		
0	00 ± 00^{a}	00 ± 00^{a}	00 ± 00^{a}	00 ± 00^{a}
5	00 ± 00^{a}	1.25 ± 1.25 ^{a}	18.75 ± 6.88^{ab}	26.25 ± 6.75^{ab}
10	00 ± 00^{a}	2.50 ± 2.50 ^{a}	30.00 ± 5.40^{bc}	38.75 ± 8.25^{bc}
20	00 ± 00^{a}	5.00 ± 2.04 ^{a}	58.75 ± 7.46 ^{de}	66.25 ± 11.96^{cd}
40	1.25 ± 1.25^{a}	11.25 ± 4.27 ^{a}	80.00 ± 4.08^{e}	91.25 ± 4.27^{d}
A. indica (5 g/kg)	00 ± 00^{a}	6.25 ± 2.04^{a}	51.25 ± 4.27^{cd}	70.00 ± 3.53^{d}
$F_{(4,15)}$	1.00^{ns}	2.50^{ns}	30.36***	23.32***

Means in the same column followed by the same letter do not differ significantly at p = 0,05 (Tukey's test) ns: non significant $P > 0.05$; ***: $P<0.001$.

Inhibition of F_1 progeny

The number of emerged adults of *S. zeamais* generally decreased ($P<0.05$) with ascending contents of the seed powders from *L. lanceolata* and *B. aegyptiaca* (Table 2). *B. aegyptiaca* seed powder inhibited *S. zeamais* adult emergence from 89 to 99% when the content increased from 5 to 40 g/kg, while for *L. lanceolata* at the same content range, *S. zeamais* F_1 progeny production varied from 84-96%. The rate of *S. zeamais* progeny suppression by *A. indica* seed powder was similar to those of the two test plant powders.

Table 2: Mean percentage reduction of F_1 progeny in maize grains treated with *Balanites aegyptiaca* and *Lophira lanceolata* seed powders

Mean (%) of the F_1 reduction of *Sitophilus zeamais*		
Seeds powder (g/kg)	***Balanites aegyptiaca***	***Lophira lanceolate***
0	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
5	86.97 ± 3.05^{b}	79.80 ± 5.19^{b}
10	95.72 ± 2.01^{c}	84.29 ± 3.89^{bc}
20	97.80 ± 1.61^{c}	87.88 ± 3.35^{bc}
40	98.44 ± 1.01^{c}	95.93 ± 1.50^{c}
A. indica (5 g/kg)	92.20 ± 1.26^{bc}	86.11 ± 1.37^{bc}
$F_{(4,15)}$	484.46***	*133.98****

Means in the same column followed by the same letter do not differ significantly at the 5% level. ***: $P<0.001$ (Tukey's test).

Damage caused to maize seeds by *Sitophilus zeamais*

Maize grains treated with the seed powders of *L. lanceolata* and *B. aegyptiaca* lost significantly ($F_{(4,15)} = 56.32$; $P<0.001$) less weight compared to the positive control (Table 3). Relative to the negative control, the treatment with 5 g/kg of the seed powder from *L. lanceolata*, *B. aegyptiaca* and *A. indica* reduced maize grain loss caued by *S. zeamais* by 2.8-fold, 2.6-fold and 9.1-fold. With the highest tested content of 40 g/kg, a 7.4-fold and 9.6-fold reduction in weight loss were recorded for the grains respectively treated with *L. lanceolata* and *B. aegyptiaca*.

Table 3: Mean percentage of maize weight loss due to *Sitophilus zeamais* exposed to *Balanites aegyptiaca* and *Lophira lanceolata* seed powders and stored for six months

Powders (g/kg)	Weight loss	
	B. aegyptiaca	***L. lanceolata***
0	21.50 ± 1.29^{c}	22.10 ± 2.28^{d}
5	7.73 ± 1.59^{ab}	8.52 ± 0.98^{c}
10	5.42 ± 1.20^{ab}	6.06 ± 0.16^{bc}
20	3.08 ± 0.06^{a}	4.65 ± 0.44^{ab}
40	2.23 ± 0.32^{a}	2.97 ± 0.56^{a}
A. indica (5 g/kg)	2.37 ± 0.66^{a}	3.97 ± 0.56^{ab}
$F_{(4,15)}$	56.32***	91.78***

In the same column means followed by the same letter do not differ signicantly at the 5% level (Tukey's test). ***: $P<0.001$

Anti-feedant activity of plant powders

Table 4 indicates the proportion of grains perforated by *S. zeamais*. All the recorded weevil perforation indices (WPI) were lower than 50%, irrespective of plant species and powder content. With ascending powder contents from 5 g/kg to 40 g/kg, the percentage of grains perforated by *S. zeamais* ranged from 3.40 ± 0.86% to 0.69 ± 0.28%) for grains treated with *B. aegyptiaca* ($F_{(4,15)} = 24.990$; $P<0.001$) and from 3.54 ± 0.24% to 1.02 ± 0.19% for grains treated with *L. lanceolata* ($F_{(4,15)} = 4.531$; $P<0.001$). Weevil perforation indices reduced

with ascending powder content. For the grains treated with 5 g/kg of seed powder, the weevil perforation indices were 32.81% for *L. lanceolata*, 39.3% for *B. aegyptiaca* and 25.66% for *A. indica*. Weevil perforation indices of 7.79% and 9.45% were recorded respectively for *B. aegyptiaca* and *L. lanceolata* seed powders at the content of 40 g/kg. The highest proportion of perforated grains were found in the untreated control, which was 100%.

Table 4: Mean percentage of grains perforated by *Sitophilus zeamais* and weevil perforation index following treatment with powders of *Balanites aegyptiaca* and *Lophira lanceolate*

Doses (g/kg)	*B. aegyptiaca*	*L. lanceolata*	WPI_Bal (%)	WPI_Lop (%)
0	8.65 ± 0.27^{c}	10.79 ± 1.04^{c}	100.00	100.00
5	3.40 ± 0.86^{b}	3.54 ± 0.24^{b}	39.30	32.81
10	2.48 ± 0.52^{ab}	3.52 ± 0.35^{b}	28.67	32.62
20	1.69 ± 0.33^{ab}	2.01 ± 0.02^{ab}	19.54	18.62
40	0.69 ± 0.28^{a}	1.02 ± 0.19^{a}	7.97	9.45
A. indica (5 g/kg)	2.22 ± 0.80^{ab}	2.80 ± 0.58^{ab}	25.66	25.95
$F_{(4,15)}$	24.990***	44.531***	IPW< 50	IPW< 50

Means in the same column followed by the same letter do not differ significantly at the 5% level (Tukey's test). ***: $P<0.001$, WPI: Weevil Perforation Index, WPI_Lop: Weevil Perforation Index in grains treated with *Lophira lanceolata*, WPI_Bal: Weevil Prforation Index in grains treated with *Balanites aegyptiaca*.

Chemical compounds found in plant powders

The chemical analysis of *B. aegyptiaca* and *L. lanceolata*, revealed the presence of polyphenols, free quinones and coumarines in both plant powders at the same quantity except free quinones, which were higher in *B. aegyptiaca* (Table 5). Alcaloids, saponins and carbohydrates were found only in *B. aegyptiaca* in higher proportions; whereas anthraquinones and tannins were found only in *L. lanceolata.* Anthraquinones were the major compounds of *L. lanceolata*. Tannins and carbohydrates were found as traces respectively in *B. aegyptiaca* and *L. lanceolata.* Flavonoids, triterpenes and reducing sugars were absent in both powders.

Table 5: Families of chemical compounds identified in *Balanites aegyptiaca* and *Lophira lanceolata* seed powders

Compounds	Plant powders	
	B. aegyptiaca	*L. lanceolata*
Alcaloids	++	-
Flavonoids	-	-
Saponins	+++	-
Triterpenes and sterols	-	-
Polyphenols	+	+
Free quinones	++	+
Anthraquinones	-	++
Tannins	~	+
Carbohydrates	++	~
Reducing sugar	-	-
Coumarines	+	+

(+++) much, (++) moderate, (+) less, (~) trace, (-) absent.

Discussion

The present work describes the effects of pulverized seeds of *B. aegyptiaca* and *L. lanceolata* on the mortality, antifeedant activity and F_1 progeny production of *S. zeamais* as well as on grain damage caused by the insect. Although the seed powders proved their insecticidal efficacy against *S. zeamais*, their action was relatively slow as significant mortality was not recorded within 3 days of exposure. More so, even after 14 days of exposure, complete mortality of the weevil was not achieved; maximum moratilty was 91.25% recorded by *B. aegyptiaca* at the highest content of 40 g/kg. Other authors have reported the slow action of powdered plant parts against stored product insects. Pinto *et al.* [38] demonstrated 23% *S. zeamais* mortality caused by the powdered leaves of *Cryptocarya alba* at the rate of 40 g/kg withn 7 days of exposure. At the application rate of 40 g/kg, the powdered leaves of *Plectranthus glandulosus* caused total mortality to *S. zeamais* only after 16 days of exposure while that of *Steganotaenia araliacea* achieved 94% moratility of the weevil 32 days-post treatment [31]. Nukenine *et al.* [35, 36], also reported 80% mortality of *S. zeamais* at dosage of 40 g/kg of *P. glandulous* powder with 14 days of exposure. *Hemizygia welwitschii* pulverized leaves at dosage of 40 g/kg induced 81.25% mortality to *S. zeamais* after 14 days of exposure, but 82.50% mortality of *C. maculatus* adult was obtained 7 days post-exposure [17].

The toxicity of the two plant powders could be attributed to alkaloids, saponins, carbohydrate anthraquinones and tannins that they contain. The insects could be intoxicated with these compounds through ingestion, penetration through the cuticle and spiracles, which could all have led to death. More so, mortality could have resulted from suffocation after the mechanical blocking of the spiracles by the powdered leaves [18]. Saponins were reported to possess antifeedant, growth regulative and entomologic properties by interacting with structural cholesterol or metabolic cholesterol [9]. Bouchelta *et al.* [8] pointed out the high bioactivity of alkaloids to *Bemisia tabaci*, together with saponins and flavonoids. In the present study, alkaloids and saponins being the major compounds in *B. aegyptiaca* might have been the reason why this plant tended to more effective than *L. lanceolata* which was dominated by anthraquinones.

The pulverized seeds of *B. aegyptiaca* and *L. lanceolata* in this study seem to possess antifeedant properties, because they showed WPI values lower than 50%; they reduced the perforation of grains by the weevil. The powder of neem and chilli (5% and 10%) and basil (10%) were reported to have antifeedant effects to the 3rd larval stage of *Tribolium castaneum* [12]. Longe *et al.* [25] showed that the proportion of *Hyphantria cunea* larvae feeding on a diet containing *Ginkgo biloba* secondary metabolites was significantly lower than the number feeding on normal diet.

The two plant powders inhibited the reproduction of the weevil. They significantly reduced F_1 progeny emergence, attaining 95.93 (*L. lancealata*) and 98.44% (*B. aegyptiaca*). The plant powders on application must have covered the surface of the grains and thus, mechanically empeded *S. zeamais* from laying eggs. Ileke and Oni [19] reported plant powders coat grains, serve as food poisons and reduce the mating ability of adult insects.

The low emergence of F_1 progeny of *S. zeamais* observed in the grain treated with *B. aegyptiaca* and *L. lanceolata* seed

powders at 40 g/kg could be a result of a high concentration of active compounds they contain. The treatment of grains reduced oviposition as well as eggs hatching and embroyonic developpement [6] in addition to suppression of the development of their pre-adult stages, justifying the low F_1 emergence recorded in this test. Our results are similar to those obtained by Kaloma *et al.* [23] with the powder of *Tagetas minitiflora*, which also strongly reduced adult emergence of *S. zeamais*. Wini *et al.* [45] also found a low rate of F_1 emergence of *S. zeamais* by applying binary mixtures of *P. glandulosus* leaf powder (25%) with *Hymenocardia acida* wood ash (75%). The powder of *Cryptocarya alba* at a similar dose of 40 g/kg showed a high inhibition of the F_1 emergence of *S. zeamais* [38]. However, Asmanizar *et al.* [7] reported no F_1 emergence of *S. zeamais* using *Jatropha curcas* and *Annona muricata* seed powders at 1% concentration. Aminata *et al.* [4] demonstrated low emergence of *S. zeamais* with less than 5 insects after one month and on average 10 insects within three months of storage at 12 g/kg. The number of emerged adults decreased with ascending dosages. This could be justified because the active compounds increased with increasing powder contents, which did not allow *S. zeamais* to feed and lay eggs. Although there was practically no mortality within three days of exposure across dosage-levels, F_1 progeny production declined with increase in powder contents. This supports the contention that the seed powders possess reproduction inhibitory properties.

The low weight loss recorded on the treated grains after six months of storage appeared to be the consequence of the high rate of mortality and the low rate of emergence observed respectively during the toxicity and F_1 progeny production tests. The high weight loss was induced in grains treated with the lower concentrations, because they did not strongly influence insect mating and oviposition. *B. aegyptiaca* caused a lower weight loss in grains than *L. lanceolata*, probably because of their difference in chemical composition. Kaloma *et al.* [23] reported that maize weight loss was attributed to *S. zeamais* damages ranging from 2.29 to 3.69% due to three plant powders *Eucalyptus citriodora*, *Cupressus lucitanica* and *Tagetas minitiflora*. Similarly, Fotso *et al.* [17] reported a 4.22% of grain damage due to *S. zeamais* on maize grains treated with *H. welwitschii* leaf powder.

Azaditrachta indica seed powder and oil were reported to potent against several insects by virtue of their azadiractin contents and thus could serve as an appropriate check for plant insecticidal activity [31, 33]. In the present study, although *A. indica* powder was superior to the two test seed powders, regarding adult mortality, the two powders compare favorably with the positive control, with respect to F_1 progeny inhibition, antifeedant activity and reduction in grain weight loss.

Conclusion

The results obtained in this work have revealed that *B. aegyptiaca* and *L. lanceolata* are good stored grain protectants against the infestation of *S. zeamais*. The two seed powders were sufficiently insecticidal and greatly reduced F_1 progeny production of the weevil, and significantly reduced the feeding activity of *S. zeamais*. That *B. aegyptiaca* and *L. lanceolata* are locally available and accessible, coupled with their good potentials as insecticides, make them suitable to be included in post-harvest protection practices.

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