**Repellency potential of some botanicals against the maize weevil,
Sitophilus zeamais (MOTSCHULSKY, 1855) (Coleoptera: Curculionidae)
in stored sorghum**

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ABSTRACT. Repellency of *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia* along with permethrin powder against *Sitophilus zeamais* was evaluated in the laboratory at 28–32°C and 60–75% RH. The botanicals were applied as powders, methanolic, ethanolic and aqueous extracts at the rate of 2.5, 5.0 and 10.0 x 10⁴ ppm per 20 g of sorghum grains, while the permethrin powder was applied at 0.056 x 10⁴ ppm. Percentage repellency was recorded at 1, 6, 12 and 24 hours after exposure (HAE). All the botanicals were found to have a repellent effect against *Sitophilus zeamais* at all three concentrations. The highest (82.22 ± 2.22%) repellency among the botanical powders was exhibited by 10.0 x 10⁴ ppm of *Euphorbia balsamifera* within 24 HAE. Methanolic leaf extracts were found to be more effective than the other formulations, causing total repellency against the weevils at 10.0 x 10⁴ ppm of all the botanicals, while the activities of the aqueous extracts were the least repellent (41.37 ± 7.39 to 60.14 ± 1.64%) after 24 hours of exposure. The repellent activities of the botanicals decreased with increasing exposure periods for powders and aqueous extracts, and increased with increasing duration for methanolic and ethanolic extracts. The results showed that the botanicals were good repellents against *Sitophilus zeamais* and could serve as stored sorghum protectants against maize weevil infestation. Grains protected with these botanicals could be used as seeds for planting. Meanwhile, studies on the toxicity of these botanicals against higher animals are recommended.

KEY WORDS: Botanicals, Extracts, Powders, Repellency, *Sitophilus zeamais*, Sorghum grains.

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INTRODUCTION

Repellents of botanical origin are desirable chemicals as they offer protection with minimal impact on the ecosystem, and as they drive away the insect pests from the treated materials by stimulating olfactory or other receptors of insects (RAJASHEKAR et al. 2012). The repellency of plant material has been exploited for thousands of years by man, simply by hanging bruised plants in houses, a practice that is still in wide use throughout the developing countries (MAIA & MORE 2011). Repellents of plant origin are considered safe in pest control, minimize pesticide residue, and ensure the safety of people, food and the environment (TALUKDAR 2006). JAYANHI et al. (2014) explained that volatile odour components of plants play a pivotal role in host identification and acceptance by insects. Acceptable host-plant odours, in combination with their environmental cues, can be attractive to insects, whereas non-host odours can either repel insects or have no effect on their behaviour (KUHS et al. 2016). These odour cues can be exploited to alter how insects perceive their landscape (JAYANHI et al. 2014). GOVINDARJAN et al. (2011) reported that more than 1 005 plant species possess insecticidal properties, 384 contain antifeedants, 297 repellents, and 27 possess growth inhibitors. ZOUBIRI & BAALIUMER (2014) reviewed the potential insecticidal properties of 230 plant species: 12 of them were reported to repel some insect pests. OBICO & RAGRAGIO (2014) found seven plant species to be the most important ones used as insect repellents, including *Leucaena leucocephala* (LAM.) DE WILT, *Gliricidia sepium* (JACQ.) WALP., *Eucalyptus* sp., *Gmelina arborea* ROXB., *Azadirachta indica* A. JUSS. and *Phyllodium pulchellum* (L.) DESV. These species contain a number of bioactive compounds like terpenoids, alkaloids, glycosides, phenols, tannins and flavonoids in their leaves, stems, bark, seeds and oil (VERA et al. 2016).

In the tropics, several plant products have been employed in subsistence agriculture for the protection of stored grains against a number of storage insects, and their success rate has been encouraging (LALE 2006). Repellent actions of some plant materials against *Sitophilus* spp. infesting stored grains have recently been reported (MWANGANGI & MUTISYA 2013, ANKUTSE 2014, ARYANI & AUAMCHAROEN 2016).

SULEIMAN et al. (2012) revealed the repellency potentials of leaf powders of *Euphorbia balsamifera* AITON and *Lawsonia inermis* L. against *Sitophilus zeamais* (MOTSCHULSKY, 1855). The repellent action of some plant products might be due to the volatility of the pungent smell, which elicits a reversible reaction in insects (ASAWALAM & EMOSAIRUE, 2006). However, information on the repellency actions of leaf powders and extracts of the plant species chosen for this study against *S. zeamais* is scanty. Therefore, this study was conducted to evaluate the repellency potential of leaf powders as well as methanolic, ethanolic and aqueous extracts of *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* (L.) DC. and *Senna obtusifolia* (L.) H.S.IRWIN & BARNEBY against *Sitophilus*

zeamais infesting sorghum grains in order to ascertain their protectant potential during the post-harvest period.

MATERIALS AND METHODS

Rearing of the insects for the experiments

Fifty pairs of *Sitophilus zeamais* were obtained from infested grain stores at Katsina Central Market, Nigeria, and then introduced into rearing bottles (500 ml), each containing 250 g of disinfested sorghum grains. The bottles were covered with pieces of muslin cloth and kept in an incubator for oviposition at 30°C and 70% R.H. for 14 days, after which the parents were removed (GOFTISHU & BELETE 2014). The bottles were maintained in the incubator under the same conditions until adult emergence. The seven-day-old progeny were sieved from the infested grains and used for the experiments.

Preparation of the botanicals for the experiments

Fresh leaves of *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia* were collected from an uncultivated area around Umaru Musa Yar'adua University, Katsina (UMYUK), Nigeria. The leaves were rinsed with distilled water to remove any dust and unwanted particles. They were then shade-dried at room temperature for 14 days. The dried leaves were ground into powder using a laboratory blender (Model 8010ES) and sieved into fine powder using a laboratory sieve with an 80-micron mesh. The powders were kept separately in plastic bottles at room temperature (PARUGRUG & ROXAS 2008).

One hundred grams of each of the plant powders was dissolved in 400 ml of methanol, ethanol and distilled water in conical flasks. The mouths of the flasks were securely corked and kept in the laboratory at room temperature for 48 hours. The extracts were separated using muslin cloth and filtered with Whatman No.1 filter papers using a vacuum pump (Dymax 14) as described by KHALIQ et al. (2014). The filtrate was separately concentrated by evaporating excess solvents using a rotary evaporator with a rotary speed of 3 to 6 rpm for 8 hours. When the contents had almost completely evaporated, aliquots were poured into evaporating dishes and placed in a water bath to evaporate the remaining/excess solvents. The resulting extracts were air-dried to remove traces of the solvent and were then stored in a refrigerator at 4°C (ABOU-ELNAGA 2015) prior to use in the repellency tests.

Repellency Tests

Determination of repellent activities of botanical powders against Sitophilus zeamais

The methods of REJITHA et al. (2014) were employed for testing the repellency potentials of powdered *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia*. An apparatus consisting of three plastic bottles (100 ml) connected by two plastic tubes 15 cm long and 1 cm in diameter at 180° was designed for each treatment. The three plastic bottles were labelled A, B and C, with B as the central chamber. Twenty grams (20 g) of sorghum grains were placed in bottle A of each apparatus mixed with different concentrations of 2.5, 5.0 and 10.0 x 10⁴ ppm equivalent to 2.5, 5.0 and 10.0% weight per weight (w/w), respectively, of *Euphorbia balsamifera* leaf powder. The concentrations were chosen based on recommendations of DALES (1996) that dry powdered material should be added to a commodity at the rate of 1 to 5% (w/w). Another 20 g of sorghum grains without any powder was placed in C – this served as a control. Ten adult *Sitophilus zeamais* obtained from the rearing phase of the experiment were introduced into bottle B. The same set-ups were made for each of *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia*, while 0.056 x 10⁴ ppm (equivalent to 50 g / 90 kg) of permethrin powder, as recommended by MUTAMBUKI & NGATIA (2012) was added to another 20 g grains as a chemical check. All treatments and controls were replicated four times.

Determination of repellent activities of botanical extracts against Sitophilus zeamais

For the extract treatments, methanolic, ethanolic and aqueous crude extracts of each of the four botanicals were diluted to three different concentrations of 2.5, 5.0 and 10.0 x 10⁴ ppm (2.5, 5.0, and 10.0% w/v). The concentrations were made by diluting 0.5, 1.0 and 2.0 g of crude extracts of *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia* in 20 ml methanol, ethanol and distilled water to obtain 2.5, 5.0 and 10.0 x 10⁴ ppm, respectively. Two ml of each of the extracts was taken using a micropipette and added to 20 g of sorghum grains in bottle A. The grains were vigorously stirred using a glass rod to ensure proper mixing with the extracts and then air-dried for one hour. Another 20 g of grains without any botanical extract were placed in bottle C to serve as a control. The treatments were replicated four times in which ten adult *Sitophilus zeamais* were introduced to bottle B, from where their direction of movement to either bottle A or C was observed at 28-32°C and 60-75% R.H.

In both powder and extract treatments, the number of weevils moving from bottle B to either bottle A or C was recorded at 1, 6, 12 and 24 hours after exposure. Percentage Repellency (PR) was calculated according to the methods of SAKUMA & FUNKAMI (1985):

$$PR = 1 - \frac{NT}{NT + NC} \times 100$$

where:

PR = Percentage Repellency

NT = Number of insects in the chemical-treated test chamber

NC = Number of insects in the control test chamber

Data analysis

The data collected were analysed using GraphPad Prism (version 7.03). They were first tested for normality using the Shapiro-Wilk normality test. One-way ANOVA was used to test significant differences that existed between the percentage repellency of different concentrations of *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia* and within the botanicals at individual concentrations against *Sitophilus zeamais* after every exposure period. Two-way ANOVA was also employed to test the level of significance in percentage repellencies among the botanicals at different concentrations. Bonferroni's multiple comparisons test was used to separate significantly different means at the 5% level of significance.

RESULTS

Repellent activities of botanical powders against *Sitophilus zeamais*

The percentage repellency of *Euphorbia balsamifera* powder ranged from 79.73 ± 3.28 to $83.09 \pm 1.17\%$ at 2.5×10^4 ppm, from 81.01 ± 2.32 to $86.67 \pm 4.51\%$ at 5.0×10^4 ppm and from 82.22 ± 2.22 to $94.10 \pm 3.42\%$ at 10×10^4 ppm within 24 HAE (Table 1).

Table 1 shows that leaf powders of *Lawsonia inermis* repelled adult *Sitophilus zeamais* to varying degrees after different exposure periods. The percentage repellency of the botanical powder from one to 24 HAE ranged from 63.34 ± 1.93 to $80.42 \pm 7.08\%$ at 2.5×10^4 ppm, from 68.20 ± 4.03 to $90.83 \pm 5.34\%$ at 5.0×10^4 ppm and from 77.78 ± 2.83 to $92.26 \pm 4.50\%$ at 10.0×10^4 ppm.

The repellent action of *Mitracarpus hirtus* leaf powder from 1 to 24 HAE varied for different concentrations. Repellency was from 47.50 ± 4.79 to $90.63 \pm 5.98\%$ at 2.5×10^4 ppm, from 50.00 ± 4.08 to $92.26 \pm 4.50\%$ at 5.0×10^4 ppm and from 71.75 ± 6.18 to $93.30 \pm 3.88\%$ at 10.0×10^4 ppm (Table 1).

Application of *Senna obtusifolia* at the three concentrations showed different repellency levels across the exposure periods: the recorded ranges were from 40.49 ± 1.44 to $63.54 \pm 5.21\%$ at 2.5×10^4 ppm, from 43.19 ± 1.19 to $72.09 \pm 3.29\%$ at 5.0×10^4 ppm and from 46.51 ± 3.70 to $77.50 \pm 3.69\%$ at 10.0×10^4 ppm (Table 1).

Table 1. Mean repellency of botanical powders applied at different concentrations against *Sitophilus zeamais* within 24 hours. Conc. – concentration ($\times 10^4$ ppm).

Treatments	Conc.	Mean Repellency (% $\pm$ S. E.)			
		Exposure Period (HAE)			
		1	6	12	24
<i>Euphorbia</i>	2.5	83.09 $\pm$ 1.17 ^a	81.16 $\pm$ 3.62 ^{ab}	80.32 $\pm$ 1.87 ^{ab}	79.73 $\pm$ 3.28 ^{ab}
<i>balsamifera</i>	5.0	86.67 $\pm$ 4.51 ^a	83.93 $\pm$ 3.01 ^{ab}	82.54 $\pm$ 1.68 ^{ab}	81.01 $\pm$ 2.32 ^a
	10.0	94.10 $\pm$ 3.42 ^a	88.82 $\pm$ 0.51 ^a	86.25 $\pm$ 2.17 ^a	82.22 $\pm$ 2.22 ^a
<i>Lawsonia</i>	2.5	80.42 $\pm$ 7.08 ^{ab}	80.36 $\pm$ 6.60 ^{ab}	72.36 $\pm$ 2.49 ^b	63.34 $\pm$ 1.93 ^b
<i>inermis</i>	5.0	90.83 $\pm$ 5.34 ^a	84.29 $\pm$ 6.00 ^{ab}	80.61 $\pm$ 3.72 ^{ab}	68.20 $\pm$ 4.03 ^b
	10.0	92.26 $\pm$ 4.50 ^a	88.30 $\pm$ 4.21 ^a	81.11 $\pm$ 2.65 ^{ab}	77.78 $\pm$ 2.83 ^{ab}
<i>Mitracarpus</i>	2.5	90.63 $\pm$ 5.98 ^a	80.46 $\pm$ 2.46 ^{ab}	79.07 $\pm$ 2.31 ^{ab}	47.50 $\pm$ 4.79 ^c
<i>hirtus</i>	5.0	92.26 $\pm$ 4.50 ^a	86.71 $\pm$ 4.73 ^a	79.62 $\pm$ 2.27 ^{ab}	50.00 $\pm$ 4.08 ^c
	10.0	93.30 $\pm$ 3.88 ^a	89.72 $\pm$ 4.09 ^a	81.11 $\pm$ 2.65 ^{ab}	71.75 $\pm$ 6.18 ^{ab}
<i>Senna</i>	2.5	63.54 $\pm$ 5.21 ^b	61.18 $\pm$ 2.33 ^c	55.63 $\pm$ 4.00 ^c	40.49 $\pm$ 1.44 ^c
<i>obtusifolia</i>	5.0	72.09 $\pm$ 3.29 ^{ab}	67.38 $\pm$ 2.71 ^b	63.68 $\pm$ 3.11 ^c	43.19 $\pm$ 1.19 ^c
	10.0	77.50 $\pm$ 3.69 ^{ab}	69.45 $\pm$ 2.78 ^b	66.88 $\pm$ 3.44 ^{bc}	46.51 $\pm$ 3.70 ^c
Permethrin	0.056	100.00 $\pm$ 0.00 ^a	96.43 $\pm$ 3.57 ^a	90.18 $\pm$ 6.08 ^a	75.36 $\pm$ 1.76 ^b

Means in the same column followed by a different letter superscript are significantly different at $p < 0.05$ by the Bonferroni multiple comparisons test.

The permethrin powder applied at 0.056×10^4 ppm showed complete ($100.00 \pm 0.00\%$) repellency against *Sitophilus zeamais* at the end of one HAE but decreased to $75.36 \pm 1.76\%$ at 24 HAE (Table 1).

Table 1 shows that the repellency of the powders at concentrations 2.5, 5.0 and 10×10^4 ppm within 24 HAE decreased in the order *Euphorbia balsamifera* > *Lawsonia inermis* > Permethrin > *Mitracarpus hirtus* > *Senna obtusifolia*.

At the end of 24 HAE, analysis of variance showed that the difference among the repellency levels of the botanical powders applied at varying concentrations was significant ($F(4, 12) = 63.49$, $p < 0.001$). Bonferroni's multiple comparisons test indicated that the percentage repellencies of *Euphorbia balsamifera* at 5.0 and 10.0×10^4 ppm were the same and that both were higher than the other treatments within 24 hours. The multiple comparisons also showed that permethrin powder had the same repellency level as *Lawsonia inermis* at 5.0 and 10.0×10^4 ppm.

Repellency of methanolic extracts of the botanicals against *Sitophilus zeamais*

The repellent activities of methanolic leaf extracts of the four plant species against *S. zeamais* varied within 24 hours of exposure. The results in Table 2 show that the repellency of *Euphorbia balsamifera* varied between 70.42 ± 4.43 and $96.43 \pm 3.57\%$ at 2.5×10^4 ppm, between 77.50 ± 3.69 and $100.00 \pm 0.00\%$ at 5.0×10^4 ppm and between 83.93 ± 5.92 and $100.00 \pm 0.00\%$ at 10.0×10^4 ppm.

The repellency actions of *L. inermis* showed that an application rate of 2.5×10^4 ppm repelled from 70.84 ± 2.41 to $96.88 \pm 3.13\%$ weevils; the percentage repellency increased from 77.44 ± 2.64 to $100.00 \pm 0.00\%$ at 5.0×10^4 ppm. At 10.0×10^4 ppm, *Lawsonia inermis* resulted in 91.67 ± 4.81 to $100.00 \pm 0.00\%$ percentage repellency within 24 hours of exposure (Table 2).

Table 2. Mean repellency of methanolic botanical extracts applied at different concentrations against *Sitophilus zeamais* within 24 hours of exposure. Conc. – concentration ($\times 10^4$ ppm).

Treatments	Conc.	Mean Repellency (% $\pm$ S. E.)			
		Exposure Period (HAE)			
		1	6	12	24
<i>Euphorbia</i>	2.5	70.42 ± 4.43^b	84.58 ± 5.42^{ab}	91.67 ± 4.81^{ab}	96.43 ± 3.57^a
<i>balsamifera</i>	5.0	77.50 ± 3.69^{ab}	88.09 ± 4.01^{ab}	95.83 ± 4.17^{ab}	100.00 ± 0.00^a
	10.0	83.93 ± 5.92^{ab}	92.86 ± 4.13^a	100.00 ± 0.00^a	100.00 ± 0.00^a
<i>Lawsonia</i>	2.5	70.84 ± 2.41^b	85.83 ± 4.79^{ab}	95.83 ± 4.17^{ab}	96.88 ± 3.13^a
<i>inermis</i>	5.0	77.44 ± 2.64^{ab}	88.69 ± 6.97^{ab}	96.43 ± 3.57^{ab}	100.00 ± 0.00^a
	10.0	91.67 ± 4.81^a	95.83 ± 4.17^a	100.00 ± 0.00^a	100.00 ± 0.00^a
<i>Mitracarpus</i>	2.5	69.17 ± 3.63^b	76.25 ± 1.25^b	86.67 ± 4.51^{ab}	92.26 ± 4.50^a
<i>hirtus</i>	5.0	76.61 ± 2.09^{ab}	77.50 ± 1.44^b	91.43 ± 5.09^{ab}	96.43 ± 3.57^a
	10.0	81.67 ± 0.96^{ab}	87.50 ± 4.17^{ab}	95.00 ± 5.00^{ab}	100.00 ± 0.00^a
<i>Senna</i>	2.5	67.09 ± 3.07^b	74.17 ± 2.76^b	79.58 ± 1.72^b	85.83 ± 4.79^a
<i>obtusifolia</i>	5.0	74.53 ± 3.31^{ab}	77.50 ± 3.69^b	82.26 ± 1.39^b	90.83 ± 5.34^a
	10.0	80.42 ± 1.97^{ab}	85.83 ± 4.79^{ab}	95.83 ± 4.17^{ab}	100.00 ± 0.00^a

Means in the same column followed by a different letter superscript are significantly different at $p < 0.05$ by the Bonferroni multiple comparisons test.

The use of *Mitracarpus hirtus* at 2.5×10^4 ppm repelled 69.17 ± 3.62 , 76.25 ± 1.25 , 86.67 ± 4.51 and $92.26 \pm 4.50\%$ weevils at 1, 6, 12 and 24 HAE, respectively. At 5.0×10^4 ppm, the percentage repellencies recorded within 1, 6, 12 and 24 HAE were 76.61 ± 2.09 ,

77.50 $\pm$ 1.44, 91.43 $\pm$ 5.09 and 96.43 $\pm$ 3.57%. Increasing the application rate to 10.0 $\times$ 10⁴ ppm resulted in the repelling of from 81.67 $\pm$ 0.96 to 100.00 $\pm$ 0.00% weevils within 24 HAE (Table 2).

The results presented in Table 2 show that the repellency levels of *Senna obtusifolia* varied within 24 HAE. Application of 2.5 $\times$ 10⁴ ppm of the botanical repelled from 67.09 $\pm$ 3.07 to 85.83 $\pm$ 4.79% weevils from 1 to 24 HAE. The percentage repellency of the botanical at the concentration of 5.0 $\times$ 10⁴ ppm varied between 74.53 $\pm$ 3.31 and 90.83 $\pm$ 5.34%. The highest repellency was recorded at 10.0 $\times$ 10⁴ ppm of the botanical and ranged from 80.42 $\pm$ 1.97 to 100.00 $\pm$ 0.00%.

Analysis of variance showed that the repellency levels of methanolic extracts of the botanicals at different concentrations against *Sitophilus zeamais* within 24 hours of exposure were not significantly different ($F(3, 9) = 2.153, p = 0.1636$).

Repellency of ethanolic extracts of the botanicals against *Sitophilus zeamais*

Table 3 shows that *Euphorbia balsamifera* applied at 2.5 $\times$ 10⁴ ppm repelled 88.75 $\pm$ 6.58 to 93.65 $\pm$ 3.72% *Sitophilus zeamais* from 1 to 24 hours of treatment. Application of the botanical at 5.0 $\times$ 10⁴ ppm resulted in a percentage repellency of 90.83 $\pm$ 5.34 to 100.00 $\pm$ 0.00%. This was slightly higher at 10.0 $\times$ 10⁴ ppm and recorded as 92.26 $\pm$ 4.50 100.00 $\pm$ 0.00% from 1 to 24 hours HAE.

As shown in Table 3, the percentage repellencies of *Lawsonia inermis* at a concentration of 2.5 $\times$ 10⁴ ppm against *Sitophilus zeamais* within 1, 6, 12 and 24 HAE were 82.50 $\pm$ 5.95, 83.75 $\pm$ 5.54, 85.91 $\pm$ 1.14 and 87.05 $\pm$ 0.45%, respectively. At 5.0 $\times$ 10⁴ ppm of the botanical, the percentage repellency increased and varied between 85.83 $\pm$ 4.79 and 94.10 $\pm$ 3.42% within 24 HAE. The highest repellency was recorded in treatments of 10.0 $\times$ 10⁴ ppm and ranged from 90.83 $\pm$ 5.34 to 97.50 $\pm$ 2.50% to 24 HAE.

Mitracarpus hirtus repelled 77.50 $\pm$ 1.44 to 86.25 $\pm$ 2.17% *Sitophilus zeamais* from 1 to 24 HAE at 2.5 $\times$ 10⁴ ppm. At 5.0 $\times$ 10⁴ ppm, the botanical repelled from 79.58 $\pm$ 1.72 to 85.08 $\pm$ 1.85% and at 10.0 $\times$ 10⁴ ppm the repellency was from 82.26 $\pm$ 1.39 to 90.00 $\pm$ 4.08% (Table 3).

The repellency of *Senna obtusifolia* followed the same pattern as that of the other botanicals, where it ranged from 80.42 $\pm$ 7.08 to 92.50 $\pm$ 2.50% at 2.5 $\times$ 10⁴ ppm, from 83.75 $\pm$ 5.54 to 93.93 $\pm$ 3.61% at 5.0 $\times$ 10⁴ ppm and from 85.42 $\pm$ 5.24 to 100.00 $\pm$ 0.00% at 10.0 $\times$ 10⁴ ppm within 1, 6, 12 and 24 HAE (Table 3).

The varying concentrations of ethanolic extracts showed different degrees of repellency against the maize weevils within 24 hours of exposure. At 2.5 $\times$ 10⁴ ppm, *Euphorbia balsamifera* had the highest repellency, followed by *Senna obtusifolia*, *Lawsonia inermis* and *Mitracarpus hirtus*. At 5.0 and 10.0 $\times$ 10⁴ ppm, the decreasing order of repellent action was *Euphorbia balsamifera* > *Lawsonia inermis* > *Senna obtusifolia* > *Mitracarpus hirtus*.

Table 3. Mean repellency of ethanolic botanical extracts applied at different concentrations against *Sitophilus zeamais* within 24 hours of exposure. Conc. – concentration ($\times 10^4$ ppm).

Treatments	Conc.	Mean Repellency (% $\pm$ S. E.)			
		Exposure Period (HAE)			
		1	6	12	24
<i>Euphorbia</i>	2.5	88.75 $\pm$ 6.58 ^a	88.75 $\pm$ 6.58 ^a	91.67 $\pm$ 4.81 ^{ab}	93.65 $\pm$ 3.72 ^{ab}
<i>balsamifera</i>	5.0	90.83 $\pm$ 5.34 ^a	92.26 $\pm$ 4.50 ^a	100.00 $\pm$ 0.00 ^a	100.00 $\pm$ 0.00 ^a
	10.0	92.26 $\pm$ 4.50 ^a	96.43 $\pm$ 3.57 ^a	100.00 $\pm$ 0.00 ^a	100.00 $\pm$ 0.00 ^a
<i>Lawsonia</i>	2.5	82.50 $\pm$ 5.95 ^a	83.75 $\pm$ 5.54 ^a	85.91 $\pm$ 1.14 ^b	87.05 $\pm$ 0.45 ^b
<i>inermis</i>	5.0	85.83 $\pm$ 4.79 ^a	90.83 $\pm$ 5.34 ^a	91.32 $\pm$ 2.91 ^{ab}	94.10 $\pm$ 3.42 ^b
	10.0	90.83 $\pm$ 5.34 ^a	92.22 $\pm$ 4.84 ^a	95.00 $\pm$ 2.89 ^a	97.50 $\pm$ 2.50 ^a
<i>Mitracarpus</i>	2.5	77.50 $\pm$ 1.44 ^a	81.25 $\pm$ 6.25 ^a	84.73 $\pm$ 1.63 ^b	86.25 $\pm$ 2.17 ^b
<i>hirtus</i>	5.0	79.58 $\pm$ 1.72 ^a	82.86 $\pm$ 1.65 ^a	85.08 $\pm$ 1.85 ^b	87.22 $\pm$ 2.42 ^b
	10.0	82.26 $\pm$ 1.39 ^a	85.32 $\pm$ 1.32 ^a	87.68 $\pm$ 0.88 ^{ab}	90.00 $\pm$ 4.08 ^{ab}
<i>Senna</i>	2.5	80.42 $\pm$ 7.08 ^a	83.75 $\pm$ 5.54 ^a	86.67 $\pm$ 4.51 ^{ab}	92.50 $\pm$ 2.50 ^{ab}
<i>obtusifolia</i>	5.0	83.75 $\pm$ 5.54 ^a	86.67 $\pm$ 4.51 ^a	92.26 $\pm$ 4.50 ^{ab}	93.93 $\pm$ 3.61 ^{ab}
	10.0	85.42 $\pm$ 5.24 ^a	90.83 $\pm$ 5.34 ^a	95.83 $\pm$ 4.17 ^a	100.00 $\pm$ 0.00 ^a

Means in the same column followed by a different letter superscript are significantly different at $p < 0.05$ by the Bonferroni multiple comparisons test.

Two-way ANOVA showed that the difference in repellency levels among ethanolic extracts of the botanicals at the three concentrations – 2.5, 5.0 and 10.0×10^4 ppm – was highly significant ($F(3, 9) = 7.268$, $p < 0.0001$) within 24 hours.

Mean separation by the Bonferroni multiple comparisons test indicated that at 5.0×10^4 ppm, the percentage repellency of *E. balsamifera* was statistically higher than those of *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia*, while those of *Lawsonia inermis* and *Mitracarpus hirtus* were the same within 24 HAE. However, at 2.5×10^4 ppm, the mean percentage repellencies of *Euphorbia balsamifera* and *Senna obtusifolia* were the same and were both higher than those of *Lawsonia inermis* and *Mitracarpus hirtus* after 24 hours of exposure (Table 3).

Repellency of aqueous extracts of the botanicals against *Sitophilus zeamais*

The percentage repellency of *Euphorbia balsamifera* decreased across the exposure periods and ranged from 48.89 ± 3.96 to $68.90 \pm 2.73\%$ at 2.5×10^4 ppm, from 56.95 ± 3.50 to $75.95 \pm 9.29\%$ at 5.0×10^4 ppm, and from 60.14 ± 1.64 to $81.61 \pm 6.38\%$ at 10.0×10^4 ppm within 24 HAE (Table 4).

Table 4. Mean repellency of aqueous botanical extracts applied at different concentrations against *Sitophilus zeamais* within 24 hours of exposure. Conc. – concentration ($\times 10^4$ ppm).

Treatments	Conc.	Mean Repellency (% $\pm$ S. E.)			
		Exposure Period (HAE)			
		1	6	12	24
<i>Euphorbia</i>	2.5	68.90 $\pm$ 2.73 ^a	65.63 $\pm$ 1.04 ^a	58.41 $\pm$ 1.72 ^a	48.89 $\pm$ 3.96 ^a
<i>balsamifera</i>	5.0	75.95 $\pm$ 9.29 ^a	67.23 $\pm$ 3.57 ^a	62.29 $\pm$ 1.57 ^a	56.95 $\pm$ 3.50 ^a
	10.0	81.61 $\pm$ 6.38 ^a	73.75 $\pm$ 1.25 ^a	68.75 $\pm$ 3.15 ^a	60.14 $\pm$ 1.64 ^a
<i>Lawsonia</i>	2.5	65.36 $\pm$ 6.56 ^a	61.58 $\pm$ 2.02 ^a	55.91 $\pm$ 2.56 ^a	45.49 $\pm$ 2.97 ^a
<i>inermis</i>	5.0	72.92 $\pm$ 9.08 ^a	63.69 $\pm$ 4.70 ^a	56.18 $\pm$ 5.86 ^a	47.27 $\pm$ 4.17 ^a
	10.0	80.95 $\pm$ 7.23 ^a	71.88 $\pm$ 4.62 ^a	61.81 $\pm$ 5.60 ^a	58.05 $\pm$ 9.19 ^a
<i>Mitracarpus</i>	2.5	63.54 $\pm$ 5.21 ^a	56.34 $\pm$ 4.53 ^a	50.40 $\pm$ 2.60 ^a	45.77 $\pm$ 4.24 ^a
<i>hirtus</i>	5.0	72.29 $\pm$ 9.34 ^a	63.81 $\pm$ 3.23 ^a	58.73 $\pm$ 2.67 ^a	52.78 $\pm$ 4.81 ^a
	10.0	80.21 $\pm$ 7.86 ^a	65.03 $\pm$ 6.23 ^a	59.03 $\pm$ 2.00 ^a	54.52 $\pm$ 5.05 ^a
<i>Senna</i>	2.5	59.70 $\pm$ 7.51 ^a	54.91 $\pm$ 5.09 ^a	48.61 $\pm$ 5.26 ^a	41.37 $\pm$ 7.39 ^a
<i>obtusifolia</i>	5.0	65.42 $\pm$ 8.91 ^a	60.15 $\pm$ 6.96 ^a	55.68 $\pm$ 2.10 ^a	50.72 $\pm$ 3.52 ^a
	10.0	75.95 $\pm$ 6.32 ^a	70.12 $\pm$ 6.73 ^a	62.30 $\pm$ 9.11 ^a	56.39 $\pm$ 4.72 ^a

Means in the same column followed by a different letter superscript are significantly different at $p < 0.05$ by the Bonferroni multiple comparisons test.

Table 4 shows that the percentage repellency of *Lawsonia inermis* at 2.5×10^4 ppm was 65.36 ± 6.56 , 61.58 ± 2.02 , 55.91 ± 2.56 and $45.49 \pm 2.97\%$ within 1, 6, 12 and 24 HAE. Application of the botanical at 5.0×10^4 ppm repelled 47.27 ± 4.17 to $72.92 \pm 9.08\%$ of the insects. At a concentration of 10.0×10^4 ppm, the botanical had a percentage repellency of 80.95 ± 7.23 , 71.88 ± 4.62 , 61.81 ± 5.60 and 58.05 ± 9.19 within 1, 6, 12 and 24 HAE.

The percentage repellency of *Mitracarpus hirtus* at an application rate of 2.5×10^4 ppm ranged from 45.77 ± 4.24 to 63.54 ± 5.21 from 1 to 24 hours (Table 4). Increasing the concentration to 5.0×10^4 ppm resulted in repellency varying between 52.78 ± 4.81 and $72.29 \pm 9.34\%$. At 10.0×10^4 ppm of the botanical, the percentage repellency ranged from 54.52 ± 5.05 to $80.21 \pm 7.86\%$ from 1 to 24 hours of exposure (Table 4).

Table 4 shows that application of *Senna obtusifolia* resulted in repelling from 41.37 ± 7.39 to $59.70 \pm 7.51\%$ *Sitophilus zeamais* at 2.5×10^4 ppm and from 50.72 ± 3.52 to $65.42 \pm 8.91\%$ at 5.0×10^4 ppm from 1 to 24 hours. At 10.0×10^4 ppm of the botanical, the percentage repellency recorded within one hour was $75.95 \pm 6.32\%$, which decreased to 70.12 ± 6.73 , 62.30 ± 9.11 and $56.39 \pm 4.72\%$ within 6, 12 and 24 HAE.

The repellency levels of aqueous extracts of the botanicals decreased in the following order: *Euphorbia balsamifera* > *Mitracarpus hirtus* > *Lawsonia inermis* > *Senna obtusifolia*.

Analysis of variance showed that the percentage repellencies of aqueous extracts of the botanicals at concentrations of 2.5, 5.0 and 10.0 x 10⁴ ppm against *Sitophilus zeamais* after 24 hours of treatments were not significantly different ($F(3, 9) = 0.4635$, $p = 0.7148$).

DISCUSSION

All the botanicals – *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia* – exhibited repellent potential against adult *Sitophilus zeamais* in stored sorghum. The repellent activity of *Euphorbia balsamifera* and *Lawsonia inermis* leaf powders against *Sitophilus zeamais* was confirmed by SULEIMAN et al. (2012), who found that 0.3 g of leaf powders of *Euphorbia balsamifera* and *Lawsonia inermis* repelled adult *Sitophilus zeamais* after 3 hours of exposure. The findings of this study confirmed the repellency potential of some botanical powders against *S. zeamais*. PARUGRUG & ROXAS (2008) recorded the highest (7.00) repellency of *Azadirachta indica* against *Sitophilus zeamais* after 1 hour of exposure. MWANGANGI & MUTSIYA (2013) reported that basil powder was capable of repelling *S. zeamais* weevils to a distance of 6.60 cm within the first two hours of exposure. The trend of decreasing repellency of botanical powders with increasing exposure periods is in agreement with PARUGRUG & ROXAS (2008), who reported a decrease in the repellency of *Azadirachta indica* against *Sitophilus zeamais* from 7.00 after 1 hour to 3.53 after 96 hours. They also reported a decrease in the repellency rating of *Tagetes erecta* L. from 6.90 to 1.13 after 96 hours of exposure.

Methanolic extracts were strongly repellent against *Sitophilus zeamais*, in which the repellent effect of *Euphorbia balsamifera*, *Lawsonia inermis* and *Mitracarpus hirtus* was higher than that of *Senna obtusifolia*; the highest was by *Lawsonia inermis*. Although information is scanty on the repellent actions of methanolic extracts of these botanicals, repellent activities of methanolic extracts of other botanicals against *Sitophilus zeamais* and related species elsewhere have been reported. WEKESA et al. (2011) recorded 35% repellency of a methanolic extract of *Hyptis spicigera* LAM. against *Sitophilus zeamais* when applied at 100 mg / 20 g maize grains. Methanolic extracts of *Curcuma longa* L. and *Kaempferia pulchra* RIDL. rhizomes applied at 1.415 µg/cm² repelled 86.0% and 76% *Sitophilus zeamais*, respectively, at 8 hours after treatment (ARYANI & AUAMCHAROEN, 2016). Another work by GIDEON et al. (2016) revealed that methanolic extracts of *Securidaca longepedunculata* FRESEN applied at 0.10 g/ml repelled 60.27% of *Sitophilus zeamais* after 30 minutes of exposure. The findings of KARAKAS (2016) indicated the

effectiveness of methanolic extracts of dill and basil leaves in repelling adult *Sitophilus granarius* (LINNAEUS, 1758) in wheat: this was above 50% at the end of a 5-hour observation period. These findings concur with those obtained in the present study.

The present study demonstrated for the first time that ethanolic extracts of *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitracarpus hirtus* and *Senna obtusifolia* had repellency potential against *Sitophilus zeamais*. AKINBULUMA et al. (2015) reported similar observations that ethanolic extracts of *Capsicum frutescens* L. and *Dennettia tripetala* BAKER f. had repellent effects against *Sitophilus zeamais* and recorded 91.68 and 89.58% repellency of *Capsicum frutescens* and *Dennettia tripetala*, respectively. Similarly, VIGLIANCO et al. (2008) reported that ethanolic extracts of *Solanum argentinum* BITTER et LILLO repelled 55.0% of *Sitophilus oryzae* (LINNAEUS, 1763).

Aqueous extracts of all four selected botanicals were also found to be repellent against *Sitophilus zeamais*, even though the degree of repellency was lower than that of the powders, methanolic and ethanolic extracts used in this study. *Euphorbia balsamifera* remained the top botanical in repelling adult *Sitophilus zeamais* in aqueous extract formulations. DE OLIVEIRA et al. (2012) stated that an aqueous leaf extract of *Eschweilera pedicellata* (RICH.) S.A. MORI applied at 1 mg/ml concentration was repellent against *Sitophilus zeamais* after 2 hours of treatment. KARAKAS (2016) showed that aqueous extracts of dill and purple basil leaves elicited 41.38 and 38.58% repellency of *Sitophilus granarius* respectively. The repellent activity of aqueous extracts of the botanicals selected for this study agrees with the findings of PADIN et al. (2013) that aqueous extracts of nine botanicals invoked repellency of *Tribolium castaneum* (HERBST, 1797).

All the selected botanicals were found to demonstrate repellent activity against adult *Sitophilus zeamais* in stored sorghum, which could probably reduce grain attack by the weevils. The study also demonstrated that *Euphorbia balsamifera* and *Lawsonia inermis* were generally more repellent against the weevils than the other plants and exhibited a repellent effect against the weevils similar to that of permethrin.

The repellent activities of the selected botanicals could be due to the presence of non-host volatile odour components of plants that repelled insects (KUHN et al. 2016). Active ingredients, such as alkaloids, flavonoids, saponins, phenolics and tannins, have been identified in *Euphorbia balsamifera*, *Lawsonia inermis* and *Senna obtusifolia* (DOUGHARI et al. 2008, KAMBA & HASSAN 2010, RAJA et al. 2013). The bioactive compounds were found to confuse the insects' olfactory receptors so that they were unable to perceive the host odour (EFFIOM et al. 2012). It has been suggested that the toxic secondary metabolites present in extracts of botanicals such as *Bridelia micrantha* (HOCHST.) BAILL., *Chasmanthera dependens* HOCHST. and *Vernonia cinerea* (L.) LESS. were responsible for repellent action against the insect pest *Dysdercus superstitionis* (HERRICH-SCHÄFFER, 1842) (ADESINA et al. 2016).

CONCLUSION

The leaves of *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitrocarpus hirtus* and *Senna obtusifolia* formulated as powders, methanolic, ethanolic or aqueous extracts displayed repellency potential against *Sitophilus zeamais* in stored sorghum. The repellency of *Euphorbia balsamifera* was similar to that of permethrin powder and was found to be stronger than that of the other botanicals; *Senna obtusifolia* was the least repellent, even though the degree of repellency was > 50%. It was generally observed that the repellent actions of the selected botanicals were concentration-dependent: repellency increased with increasing concentration. Prolongation of exposure periods decreased the repellent actions of the botanical powders and aqueous extracts. In treatments with methanolic and ethanolic extracts, however, repellency rates were generally found to rise with increasing exposure time, showing their persistency up to the end of 24 HAE. It is therefore concluded that *Euphorbia balsamifera*, *Lawsonia inermis*, *Mitrocarpus hirtus* and *Senna obtusifolia* could be used as repellents against *Sitophilus zeamais* and could serve as protectants of stored sorghum seeds. Grains protected with these botanicals could be used as seeds for planting. Meanwhile, studies on the toxicity of these botanicals against higher animals are recommended.

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