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Efficacy of Bone Charcoal Dust of Six Mammalian Species as Eco-Friendly Alternatives to Conventional Synthetic Insecticides in the Control of *Sitophilus Zeamais* Motschulsky (Coleoptera: Curculionidae) Infesting Stored Resistant and Susceptible Maize Cultivars

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ABSTRACT

The efficacy of bone charcoal dusts of six species of mammal as eco-friendly alternatives to conventional synthetic insecticides in the management of *Sitophilus zeamais* Motschulsky infestation in stored resistant and susceptible maize cultivars was investigated in the laboratory at ambient temperature (31.8 ^{0}C) and relative humidity (70.5 %). Dry femurs and ribs of the African humped cow (*Bos indicus* Linnaeus), rabbit (*Lepus* spp L.), goat (*Capra hircus* L.), sheep (*Ovis aries* L.), dog (*Canis domesticus* L.) and pig (*Sus scrofa* L.) were burnt with fire wood (*Magnifera indica* L.). The resulting bone charcoal was ground using clean mortar and pestle, and sieved to produce the fine inert dust for the assay. Bone charcoal dusts of the animals and permethrin powder were comparatively tested at the rates of 0.25, 0.50 and 1.00 % w/w against *S. zeamais* infesting stored resistant and susceptible maize. The charcoal dusts of cow and sheep were the best at controlling *S. zeamais* infestation. After matching with the efficacy of permethrin, the study found that bone charcoal dusts of the mammals could be exploited in the control of weevil infestation in both stored resistant and susceptible maize cultivars. Complete suppression of *S. zeamais* progeny emergence and 100 % grain protection from pest-feeding were achieved with ≥ 0.25 % (w/w) of each of the animal bone charcoal dust in resistant maize stored for 54 days. However, in susceptible cultivar, higher dust concentration of ≥ 0.50 % (w/w) was needed to achieve the same results. High mortality and protection achieved by the bone charcoal dusts were attributable to weevil cuticular abrasion, active components of the bones and combustion-related factors. Class of maize cultivar stored and protected with the animal bone charcoal dusts had no obvious impact on the weevil mortality at short storage duration of < 5 days. However, at prolonged storage duration of 54 days, cultivar-effect became conspicuous in terms of adult emergence and grain damage.

Keywords: Bone Charcoal Dust, *Sitophilus Zeamais*, Permethrin, Mammals, Maize Cultivars

INTRODUCTION

Maize (*Zea mays* L.) is reportedly a staple crop (Nwosu, 2014). The grains are used primarily as food for all classes particularly in Nigeria. Beside its use as food in many countries of the world, maize is a source of livestock feed and has industrial relevance (Nwaubani and Fasoranti, 2008; Nwosu and Nwosu, 2012). Maize does not require much human commitment to thrive, its yield is often reasonable; the produce is simple to process, readily digested and more affordable than other cereals (CGIAR, 1997). These qualities have made

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maize outstanding among other cereals. Evidenced from the rush for fresh, boiled and roasted maize, its productivity in Nigeria does not seem to match the country's ever increasing population. McCann (2006) reported widespread hunger since the nineteen eighties and attributed it to decreased maize production caused by several biotic and abiotic constraints.

Insect pests are one of the most important biotic limiting factors of maize production (Pimentel, 2007). It has been reported that damage by insect pests accelerates infection with disease-causing organisms through transmission of their spores (Osipitan *et al*., 2011). Insect pests cause damage to maize grains both in the field and in storage. Comparatively, stored maize seems to be more vulnerable to insect pest attack. Among the biological systems adversely affecting maize in storage, the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) is the most important (Adedire, 2001). Infestation by the notorious stored product insect reportedly commences in the field, but most damage to grains is caused in storage (Demissie *et al*., 2008). Damaged grains are not nutritionally suitable for human consumptions and cannot be effectively utilized for agricultural and commercial purposes (Abebe *et al*., 2009). When stored maize is unprotected, *S. zeamais* has been reported to cause 20 to 90 % loss (Adedire *et al*., 2011). Losing stored maize to weevil constitutes a serious constraint to the realization of global food security. Therefore, in order to meet the demand for maize, it is necessary to tackle the problem of maize grain loss due to *S. zeamais* activity. When successful, rural incomes stand to increase and economic growth will be stimulated (Eicher and Byerlee, 1997).

Various pest control measures have been applied to address the issue of maize grain damage and loss due to *S. zeamais* (Morah and Mbata, 1982; Adedire, 2001; Demissie *et al*., 2008; Adedire *et al*., 2011; Nwosu and Nwosu, 2012; Munyiri *et al*., 2013). Among these management options, the most effective, and most commonly used, is convectional synthetic insecticides (Subramanyam and Hagstrum, 1995; Adams and Schulten, 1996; Abebe *et al*., 2009). This is associated with health, ecological and economic problems (Schwab *et al*., 1995). Search for safer alternatives in *S. zeamais* control has concentrated on botanical insecticides without attention to potentials of inert dusts of animal materials. Nwaubani and Fasoranti (2008) stressed that there was paucity of information on the use of cow bone charcoal dust in the control of stored product insect pests. Yet, inert dusts when kept dry were active against insects for a prolonged period of time (Subramanyam *et al*., 1998; Nwaubani and Fasoranti, 2008). Several authors (WHO, 1974; McLaughlin, 1994) emphasized that inert dusts were non toxic to mammals. In addition, their applications did not require specialized equipment and skill and they could easily be removed from grains during processing (Nwaubani and Fasoranti, 2008). Furthermore, inert cow bone charcoal dust used against *S. zeamais* and *Rhyzopertha dominica* Fab. (Coleoptera: Bruchidae) significantly suppressed their populations in stored maize (Nwaubani and Fasoranti, 2008). These formed the rationale for the present study. The objective of this study was, therefore, to investigate the insecticidal activities of bone charcoal dusts of six mammalian species with a view to compare efficacy level with a conventional synthetic insecticide, permethrin, and to find alternatives to the toxic insecticide to minimize environment contamination.

MATERIALS AND METHODS

Insect Culture

The insects used in the experiment, at the Research Biology Laboratory of Department of Biological Sciences, University of Agriculture, Makurdi, Benue

State, Nigeria were obtained from a stock culture of *S. zeamais* collected from the Research Laboratory of Department of Veterinary Parasitology and Entomology of the same University. This population was solely reared on a susceptible cultivar, Bende white in 3 different containers having 400 g of the maize grains. Each of the containers was covered with muslin net (held in place with cut-edge of container lid) to ensure proper ventilation and to prevent exit of the weevils and entry of unwanted organisms. After 7 days of pest-feeding and oviposition, dead and live weevils were removed and discarded. The culture was kept at ambient temperature (31.8 ^{0}C) and relative humidity (70.5 %) for adult emergence. Newly emerged of similar aged adults of *S. zeamais* were used for the experiment.

Maize Cultivars

The maize cultivars used in the study were those whose resistance status is known. Cultivar $T_2BRELD.3C_4$ is resistant against *S. zeamais* infestation and damage in stored maize (Adedire *et al*., 2011), while Bende White is susceptible to the weevil (Asawalam *et al*., 2006). Cultivar $T_2BRELD.3C_4$ was obtained from International Institute for Tropical Agriculture, Ibadan, Nigeria, while Bende White was procured from Umuahia Main Market, Abia State, Nigeria. Collected cultivars were cleaned and disinfested for one month in a refrigerator at 4 ^{0}C and acclimatized for 2 weeks in the laboratory prior to the experiment (Abebe *et al.,* 2009).

Animal Materials

Femurs and ribs of African cow (*Bos indicus*), sheep (*Ovis aries*), goat (*Capra hircus*) and pig (*Sus scrofa*) were obtained from Wurukum and Wadata Markets Makurdi, Benue State Nigeria. Dog bone (*Canis domesticus*) was collected from Abo Otukpa, Ogbadibo Local Government Area, Benue State while rabbit (*Lepus* spp) bone was extracted from live specimen bought from Chetangi Kakaki village around University of Agriculture Makurdi. Test animals were identified by Henry Ukwu, Department of Animal Production, University of Agriculture, Makurdi, Benue State, Nigeria.

Preparation of Bone Charcoal Dust

Collected bones were kept under laboratory conditions for 6 months, to achieve proper drying, before they were burnt. Burning was aided with firewood (Nwaubani and Fasoranti, 2008) and was as natural as possible in the present study. The resulting charcoal was pounded with mortar and pestle, and sieved with micro mesh of 1mm x 1mm pore. Fine inert dusts obtained were immediately used for the experiment.

Effect of Charcoal Dust on Weevil Mortality, F_1 Progeny Emergence, Larvae Development and Grain Damage:

Bone charcoal dust of each of the six species of mammal was tested against *S. zeamais* on resistant and susceptible maize grains at the rates of 0.25, 0.50 and 1.00% (w/w). A total of eight containers with 20 g of $T_2BRELD.3C_4$ maize (resistant cultivar) were first arranged on a laboratory bench. The first container was treated with 0.05 g of cow bone charcoal dust, equivalent to 0.25 % w/w. The second container was treated with 0.05 g of sheep bone charcoal dust. The third container was treated with 0.05 g of goat bone dust. The fourth container was treated with 0.05 g of rabbit bone charcoal dust. The fifth container was treated with 0.05 g of dog charcoal dust. The sixth container was treated with 0.05 g of pig dust. The seventh container was treated with 0.05 g of permetrin insecticide (from pyrethroids) and the eighth container had only 20 g of the maize grains. Treated grains were vigorously shaken for about 1 minute to ensure proper coating of grain, two hours later twenty 1 to 2 weeks old unsexed adult weevils were introduced into each container (Nwaubani and Fasoranti, 2008). Each container was covered with white muslin cloth held in place with cut-edge of container lid for adequate ventilation and to prevent exit of the weevils and entry of unwanted organisms. All treatments were replicated four times. This was repeated at the rates of 0.1 and 0.2 g (equivalent to 0.50 and 1.00 % w/w) of the bone charcoal dusts of the animals. The same set – up was made at the same rates, except that the animal bone charcoal dusts were tested on a susceptible maize cultivar (Bende White). Both set-ups received equal attention under the same laboratory conditions. Mortality counts were taken daily up to 4 days. Dead weevils were those that did not respond to probe with a pin. After the 8th day, all the weevils (dead and alive) were removed and the containers were kept for 47 days before the commencement of F_1 progeny count (Nwaubani and Fasoranti, 2008). When there was no emergence for 7 consecutive days, counting was stopped (Nwaubani and Fasoranti, 2008). Grain damage was assessed on day 54 of infestation using holes and tunnels as criteria. All the grains in the 20 g weight of each replicate were thoroughly examined. After that, the grains were soaked in water for 48 hours and broken to count and record larvae present in grains. *S. zeamais* larvae were identified using morphological characteristics (Kiritani, 1965).

Statistical Analysis

Data on percent adult weevil mortality and percent grain damage were angular-transformed while numbers of F_1 progeny and larvae were log transformed in order to stabilize the variance (Abebe *et al*., 2009). Means were separated applying the least significant difference (LSD) in a multiple range test. A probability level of 0.05 was considered in all statistical inference.

RESULTS

Impact of Bone Charcoal Dusts on *S. Zeamais* Bionomics and Damage Allowed on Resistant Maize Cultivar:

Efficacy of the bone charcoal dusts of six species of mammal were investigated at three concentration levels, 0.25, 0.50 and 1.00 % (w/w) against *S. zeamais* on a resistant maize cultivar stored for 54 days. Table (1) presents the results. There were significant differences ($P < 0.05$) among the charcoal dusts in the mean percent mortality of adults of *S. zeamais* at 0.25 % w/w after 24 hours of exposure. On the contrary, at 0.50 and 1.00 % w/w, there were no significant differences ($P > 0.05$) in percent mortality caused by the animal dusts at all assessed post treatment periods. At 0.25 % w/w, cow bone charcoal dust caused the highest adult *S. zeamais* mortality (37.5 %) at 24 hour post treatment period. Meanwhile, the conventional synthetic insecticide, permethrin killed 38.75 % of the weevils at this same concentration and exposure period. Pig bone charcoal dust killed the least (1.25 %) weevils at 0.25 % w/w after 24 hours of exposure. All the animal bone charcoal dusts investigated caused over 90 % mortality of adults of *S. zeamais* after 48 hours of exposure, reaching 100 % at 72 hour post treatment period at 0.25 % w/w. At advanced concentrations of 0.50 and 1.00 % w/w, adult weevil mortality caused by all bone charcoal dusts of the animals reached 100 % just after 24 hours of exposure. In the stored resistant maize, protected by each of the animal bone charcoal dusts, adult weevils did not emerge, larvae were not found in broken grains and grains were not damaged after 54 days of infestation. This was the same with protection by permethrin insecticide. Meanwhile, unprotected grains recorded significantly ($P < 0.05$) lowest *S. zeamais* mortality, highest number of emerged adults, highest number of larvae and highest damage.

Table (1): Effect of mammalian bone charcoal dusts on the bionomics of *S. zeamais* and grain damage suppression on a resistant maize cultivar (T_2BRELD.3C_4)

Charcoal dust rate (% w/w)		% mortality at indicated hour ±SE				No of emerged adults ±SE	No of larvae ±SE	% grain damage ±SE
		24	48	72	96			
Cow	**0.25**	37.50±0.20[a]	91.30±0.50[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Rabbit	**0.25**	28.75±2.00[b]	95.00±0.40[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Goat	**0.25**	33.75±0.30[a]	95.00±1.50[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Sheep	**0.25**	22.50±0.89[b]	91.25±0.66[a]	98.75±0.21[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Dog	**0.25**	28.75±0.70[b]	75.00±0.54[b]	92.50±0.03[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Pig	**0.25**	1.25±0.02[c]	11.25±0.04[c]	51.25±0.61[b]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Permethrin	**0.25**	38.75±7.08[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
	1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Control	**0.0**	00.00±0.00[d]	00.00±0.00[d]	00.00±0.00[c]	00.00±0.00[b]	1.00±0.10[a]	1.25±0.00[a]	1.33±0.01[a]

Comparisons were made within columns concentration by concentration among the treatments. Means followed by the same letter are not significantly (P > 0.05) different by LSD.

Impact of Bone Charcoal Dusts on *S. Zeamais* Bionomics and Damage Allowed on Susceptible Maize Cultivar:

Efficacy of the animal bone charcoal dusts were also investigated at three concentration levels, 0.25, 0.50 and 1.00 % (w/w) against *S. zeamais* in a susceptible maize cultivar stored for 54 days (Table 2). There were significant differences (P < 0.05) among the bone charcoal dusts in the mean percent mortality of adult *S. zeamais* at 0.25 % w/w after 24 hours of exposure. On the contrary, at 0.50 and 1.00 % w/w, there were no significant differences (P > 0.05) in percent mortality caused by the animal dusts at all post treatment periods assessed. At 0.25 % w/w, cow bone charcoal dust again caused the highest adult weevil mortality (65.00 %) after 24 hours of exposure. Meanwhile, the conventional synthetic insecticide, permethrin killed 80.00 % of the weevils at this same concentration and exposure period. Pig bone charcoal dust killed the least (40.00 %) weevils at 0.25 % w/w after 24 hours of exposure. All the animal bone charcoal dusts investigated caused 100 % weevil mortality after 48 hours of exposure at 0.25 % w/w. Adult weevil emergence, larvae development and grain damage occurred at the rate of 0.25 % w/w but were not observed amidst grains protected with the animal charcoal dusts at higher rates of 0.50 and 1.00 % w/w. Grains protected with pig bone charcoal dust were most vulnerable to adult emergence, larvae development and damage. Grains protected with bone charcoal dusts of cow and sheep experienced lowest adult emergence, larvae development and damage when compared to other treatments.

Table (2): Effect of mammalian bone charcoal dusts on the bionomics of *S. zeamais* and grain damage suppression on a susceptible maize cultivar (Bende White)

Charcoal dust rate (% w/w)	% mortality at indicated hour ±SE				No of emerged adults ±SE	No of larvae ±SE	% grain damage ±SE
	24	48	72	96			
Cow 0.25	65.00±0.23[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	1.00±0.02[a]	5.00±0.33[a]	1.25±1.00[a]
0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Rabbit 0.25	45.00±0.02[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	1.00±0.00[a]	2.00±0.00[b]	1.22±0.00[a]
0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Goat 0.25	45.00±0.01[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	1.00±0.00[a]	4.00±0.32[a]	1.25±0.05[a]
0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Sheep 0.25	50.00±5.99[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	1.00±0.00[a]	5.00±1.21[a]	2.25±0.02[a]
0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Dog 0.25	45.00±0.22[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	1.00±0.05[a]	5.00±2.50[a]	1.20±0.11[a]
0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Pig 0.25	40.00±0.34[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	4.00±0.00[c]	7.00±0.00[c]	7.50±0.00[b]
0.5	80.00±2.70[c]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Permethrin 0.25	80.00±0.00[c]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[b]	00.00±0.00[a]	00.00±0.00[a]
0.5	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
1.0	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]	00.00±0.00[a]
Control 0.0	00.00±0.00[d]	00.00±0.00[b]	00.00±0.00[b]	00.00±0.00[b]	127.59±0.20[d]	0.50±0.00[a]	96.25±0.20[c]

Comparisons were made within columns concentration by concentration among the treatments. Means followed by the same letter are not significantly (P > 0.05) different by LSD.

DISCUSSION

The analysis of results showed that the bone charcoal dusts of cow, rabbit, goat, sheep and dog are good materials for managing *S. zeamais* in storage. After 48 hours of exposure, the efficacy of all the animal charcoal dusts in suppressing weevil population matched that of the conventional synthetic insecticide, permethrin at concentrations of 0.50 and 1.00 % w/w in stored resistant and susceptible maize cultivars. However, at low rate of 0.25 % w/w and after 24 hours of exposure, the most effective animal bone charcoal dust, cow failed to match the efficacy of permethrin insecticide amidst susceptible maize. This suggests that the concentration of the bone charcoal dust should be increased to 0.50 % w/w to effectively kill weevils within 24 hours of exposure. The findings of the present study have shown that maize cultivar difference has no effect on adult *S. zeamais* mortality at short storage duration of less than 5 days, but at prolonged storage duration of about 54 days, maize cultivar effect became noticeable in terms of adult emergence, larvae development and grain damage.

Similar work by Nwaubani and Fasoranti (2008) strongly indicated that some animal charcoal bone dusts have insecticidal and antifeedant properties which could inhibit the activities of the maize weevil, *S. zeamais* and some other stored product insect pests. The physical abrasion of the epicuticular lipid layer of the insect pest cuticle caused by the animal bone charcoal dusts and the active components in the bones/ bone charcoal dusts might have been responsible for the insecticidal activities observed as also raised by several workers (Korunic, 1998; Nwaubani and Fasoranti, 2008). Kimball (1974) stressed that the main mineral component of the mammalian bone is calcium phosphate, although magnesium, carbonate and fluoride ions are also present. Burning of bones of the mammalian species in the study resulted in the formation of calcium oxide (quicklime). This is considered to be the key active substance in the dust. It is also possible that unknown additional lethal factors such as water-soluble fluorides from the bones as well as smoke from the combustion of the bones acted as contact insecticides after cuticular abrasion had occurred. Indeed, water-soluble fluorides have been said to enhance efficacy of inert dusts even at higher relative humidity (Ebeling and Wagner, 1959; Nwaubani and Fasoranti, 2008). Nwaubani and Fasoranti (2008) warned against the generalization of the mechanism of action of mammalian bone charcoal dust, recommending that dusts' physical properties, insect behavior and test crop variety require proper qualification. In the present study, contribution of cultivar difference was qualified in the sense that two different main classes of cultivars were tested at the same conditions to ascertain their influence on the control success of the bone charcoal dusts.

In conclusion, the class of maize cultivar stored and protected with the bone charcoal dusts had no obvious impact on the mortality of *S. zeamais* at short storage duration of < 5 days. However, at prolonged storage duration of 54 days, cultivar-effect became conspicuous in terms of adult emergence and grain damage. The study recommends the use of bone charcoal dusts of cow and sheep at concentration of $\geq$ 0.50 % (w/w) in the control of *S. zeamais* infestation and damage in any class of stored maize grains.

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كفاءة مسحوق فحم عظام ستة أنواع من الثدييات كبدائل مبيدات تقليدية مصنعة صديقة للبيئة لمكافحة حشرة السوس (غمدية الأجنحة: كيركيوليوندي) ***Sitophilus zeamais*** **motschulsky** والتي تصيب سلالات ذرة حساسة ومقاومة

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ملخص

تم إجراء التجربة في المختبر وعلى درجة حرارة 31.8°م ورطوبة نسبية 70.5%. تم تقييم كفاءة مسحوق فحم عظام ستة أنواع من الثدييات كبدائل مبيدات تقليدية مصنعة صديقة للبيئة لمكافحة حشرة السوس (غمدية الأجنحة: كيركيوليوندي) *Sitophilus zeamais* Motschulsky والتي تصيب سلالات ذرة حساسة ومقاومة.

تم حرق عظم الفخذ والضلع الجافة المأخوذة من البقرة الإفريقية ذات السنامة (*Bos indicus* Limaeus) والأرنب (*Lepus* spp L.) والماعز (*Capra hircus* L.) والضأن (*Ovis aries* L.) والكلب (*Canis domesticus* L.) والخنزير (*Sus scrofa* L.).

تم الحرق بوساطة الخشب (*Magnifera indica*).

تم طحن فحم العظام في هاون نظيف وتم تنخيله للحصول على مسحوق ناعم خامل للتجربة.

تم اختبار مسحوق فحم عظام الحيوانات المشار إليها أعلاه ومبيد (بيرميثرين) بالتركيزات: 0.25، 0.50، 1.00% وزن/ وزن لمكافحة السوسة التي تصيب الذرة المخزونة الحساسة والمقاومة. كان مسحوق الفحم من الأبقار والأغنام الأفضل في مكافحة السوسة. لدى مقارنة كفاءة المساحيق مع مبيد (بيرميثرين) أظهرت الدراسة أن مسحوق فحم الحيوانات من الممكن استعماله في مكافحة السوسة في سلالات الذرة الحساسة والمقاومة. تم الوقف الكامل لفقس الحشرة، 100% حماية من تغذية الحشرة على الذرة عند استعمال 0.25% (وزن/ وزن) من كل من مسحوق فحم عظام الحيوانات في الذرة المقاومة المخزنة لمدة (54) يوماً وعموماً، في السلالة الحساسة، ثم استعمال تركيز أكبر 0.50% وزن / وزن للحصول على نفس النتائج.

نسبة الموت العالية والوقاية عند استعمال مسحوق فحم العظام كانت بسبب خدش بشرة (cuticle) الحشرة وإلى المكونات الفعالة في العظام وإلى عوامل حرق العظام.

الذرة المخزنة والمضاف إليها مسحوق فحم العظام لم يتم ملاحظة أي تأثير على موت الحشرة في ظروف التخزين القصيرة لمدة أقل من خمسة أيام. ولكن في ظروف تخزين طويلة لمدة 54 يوماً أصبح تأثير السلالة واضحاً على نفس الحشرات الكاملة والضرر على الحبوب.

الكلمات الدالة: مسحوق فحم العظام، سوسة *Sitophilus*، بيرميثرين، ثدييات سلالة الذرة.

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