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Comparative toxicity of four local botanical powders to *Sitophilus zeamais* and influence of drying regime and particle size on insecticidal efficacy

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ABSTRACT

The toxicity of *Azadirachta indica* seed powder and leaf powders from *Plectranthus glandulosus*, *Steganotaenia araliacea* and *Annona senegalensis* to adult *Sitophilus zeamais* was determined in the laboratory. The influence of drying regime and particle size on the insecticidal efficacy of *P. glandulosus* and *S. araliacea* powders was also assessed. The seeds and leaves were either dried under shade or sunlight, pulverized until the particles passed through a 1 mm or 0.2 mm mesh-sieve. Maize grains were admixed with the powders at the rates 0, 5, 10, 20 and 40 g/kg for the assessment of mortality over a 14-d or 30-d period, as well as for population increase and damage. Within 14-d exposure, *P. glandulosus* powder caused the highest weevil mortality followed by *A. indica*. *A. indica* powder was by far more effective in reducing grain damage and population increase compared with all the other powders during three-month storage period. Powders from the leaves dried under shade compared with those dried under sunlight and the smaller compared with the larger particle size, caused higher weevil mortality. Neem seed powder and powdered leaves of *P. glandulosus* have a great potential in the protection of maize against *S. zeamais* infestation in subsistence storage systems.

Keywords: Plant products, storage pest, maize, infestation, Cameroon.

INTRODUCTION

Maize (*Zea mays* L., Poaceae) is an important cereal widely cultivated in the tropics; both for human consumption and livestock feed. It is the most important cereal in the world, Africa and Cameroon in terms of total production (FAO, 2011). In Africa, the constant availability of maize in adequate quantities is fundamental to food security. Unfortunately, increasing the supply of the crop is marred by losses during storage caused principally by insects. Among these insects,

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the cosmopolitan *Sitophilus zeamais* Motschulsky (Coleopera: Curculionidae) is one of the most destructive (Reichmuth et al., 2007). The weevil together with other insects cause an estimated 24.5% loss of maize, and damaged grains have reduced nutritional value and weight, low frequency of germination, and low market value (Yuya et al., 2009; Tefera et al., 2011: Napoleao et al., 2013). Nukenine et al. (2002) recorded mean percentage damaged grains caused by *S. zeamais* of 33% on maize stored in the Adamawa Region of Cameroon.

A commonly used method for controlling pests in stored products is the application of synthetic contact insecticides (Chaube, 2008). This has led to problems such as pest resurgence and increasing costs of application originating from the development of resistance to insecticides (Zhao et al., 2012). In addition these pesticides can have lethal effects on non-target organisms and can cause direct toxicity to applicators (Philips and Throne, 2010). These drawbacks of synthetic insecticides have stimulated intensive search for alternative measures that are safer and environmentally friendly (Isman, 2006; Obeng-Ofori, 2007). Among potential natural reduced-risk pesticides are botanical insecticides, which are products based on powders, extracts or purified substances of plant origin.

Most of the grain produced in sub-Saharan Africa comes from small-scale farmers, many of whom use different plant products for insect control (Jembere et al., 1995; Tapondjou et al., 2000; Ukeh et al., 2012). Recently, the use of these natural materials has stimulated research to establish the scientific basis targeting their efficacy, active constituents and effective application technologies (Jembere et al., 1995; Nukenine et al., 2007). The publications on plants or plant products used in storage against different storage insect pests are dominated by essential oils, pure compounds or solvent extracts, with very little on powdered materials. None of these dominant approaches account for the real life situations of resource-limited farm-families, who are more familiar with simple methods for preparing botanicals (dried materials, and in some cases powdered form) (Paul et al., 2009). Jembere et al. (1995) and Weaver and Subramanyam (2000) reported that powdering considerably enhance the effectiveness of traditional practice of adding intact, fresh leaves to stored commodities. As a corollary, smaller particles of plant materials compared to larger ones may be more effective against insect pests. The efficacy of the powdered seeds of *Piper guineense* with smaller particles (0.6 mm) against *S. zeamais* on maize was comparable with that of Pirimiphos Methyl, while the larger particles (2 mm) were ineffective (Asawalam and Emosairue, 2006).

Azadirachta indica A. Juss (Meliaceae) is an Indian tree, commonly called neem. It has many useful compounds, including azadirachtin, a tetranotriterpenoid limonoid, the active ingredient in many neem-based insecticides (Mordue and Blackwell, 1993). It possesses antifeedant, repellant, growth disrupting and larvicidal properties against a large number of pests (Mathur, 2013). The neem plant was introduced in Cameroon in 1947 (Yengué and Callot, 2002), and is widely distributed in the northern partand increasingly, in few areas in the south. Unfortunately, little is known about the use of this plant in Cameroon against insect pests , while its use in the treatment of diseases is common and has been on the rise (Noumi and Anguessin, 2010).

The leaves of *Plectranthus glandulosus* Hook f. (syn. *Coleus laxiflorus* (Benth.) Roberty) (Lamiaceae) and *Annona senegalensis* Pers. (Annonaceae) are generally used for stored grain protection in northern Cameroon (Ngamo and Hance, 2007). *P. glandulosus* is used locally in folk medicine for the treatment of colds and sore throat

(Ngassoum et al., 2001). Again, scientific evidences on the bioactivity of powders from this plant against insects are scanty. Nukenine et al. (2010a) reported good and modest insecticidal activity of *P. glandulosus* leaf powder against *S. zeamais* and *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), respectively, under fixed laboratory conditions (temperature: 25 °C and r.h.: 65-70%). The medicinal properties of *A. senegalensis* are well documented, especially in the treatment of diarrhoea, dermatitis and gastric ulcers (Suleiman et al., 2008). The insecticidal properties of the plant are also reported (Ngamo and Hance, 2007), though with little information on its leaf powder and *S. zeamais*. Petroleum and ethanolic extracts, as well as powders from the leaves of *Steganotaenia araliacea* Hochst (Araliaceae) showed significant toxic and repellent effect against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) (Abubakar et al., 2001). The crude extracts of *S. araliacea* showed anthelmintic (Monglo et al., 2006) and anti-leishmanial activity (Ndjonka et al., 2010). There is a dearth of information about the insect control properties of *S. araliacea* and only one study has reported on *S. zeamais* (Nukenine et al., 2007).

Against this background, this paper presents the results of an investigation on the effects of seed powder from *A. indica* and leaf powders from *P. glandulosus, A. senegalensis* and *S. araliacea* as toxicants against adult *S. zeamais*. The ability of the plant materials to reduce damage and suppress population increase of the weevil was also examined. In addition, the paper highlights the outcomes of drying regime and particle size of *P. glandulosus* and *S. araliacea* leaf powders on toxicity to *S. zeamais*.

MATERIALS AND METHODS

Culturing of insects

Individuals of *S. zeamais* were obtained from a laboratory stock culture, kept since 2005 at the Department of Applied Chemistry, University of Ngaoundere, Cameroon. Twenty adults of mixed sex were put in 900 ml glass jars containing 500 g of disinfested maize of the var. Shaba harvested in Belel, Adamawa region, Cameroon in December 2006. The jars were covered with nylon mesh held in place with rubber bands. After two weeks of oviposition period, the adults were removed and the progeny that emerged later were used for the different assays. The ages of the insects were known to be 14-21 d.

Collection and preparation of plant materials

The ripe fruits of *A. indica* were collected on the ground under neem trees at Kaélé, Far North Region of Cameroon in November 2006. In the same month, the non-senescent leaves of *A. senegalensis*, *P. glandulosus* and *S. araliacea* were collected in Ngaoundere, Adamawa Region, with the help of a botanist. Kaélé and Ngaoundere are located respectively in the Sudano-Sahelian and Sudano-Guinean agro-ecological zones. The Sudano-Sahelian agro-ecological zone is characterized by two seasons: wet (June to September) and dry (October to May) (IRAD, 2007). Annual rainfall ranges between 800 and 1000 mm. Annual mean temperature is 29 °C, with a maximum of 39 °C in March and minimum of 17 °C in January. Average annual relative humidity stands at 67%. The Ngaoundere area is characterized by two seasons – a dry season from November to March and a wet season spanning April to October. Average annual temperature is 22 °C with a maximum of 34 °C in March and a minimum of 12 °C in December or January. Annual precipitation is 1595 mm (Anonymous, 1981).

The neem fruits were hand-depulped and the seeds sundried for 5 days, before decortications to obtain the seed kernels. The leaves of *A. senegalensis* were dried under shade on laboratory tables for seven days, when they were crisp dry. Part of the leaves of *P. glandulosus* and *S. araliacea* was sundried for four days while the other part was dried under shade on laboratory tables for seven days. All the dried plant materials were pounded in a locally-manufactured wooden mortar. The crushed plant materials were passed through a 1-mm mesh sieve. In addition, part of the crushed leaves of *P. glandulosus* and *S. araliacea* dried under shade was further pounded until the powders passed through a 0.2-mm mesh sieve. This two mesh sizes are popularly used by farm-families in the Northern Region of Cameroon. All the plant powders were stored in a refrigerator at +4 °C until needed for bioassay.

Adult mortality bioassay

Four quantities (0.25, 0.5, 1 and 2 g) of the powders dried under shade with particle size 1 mm for each plant species were separately admixed to 50 g of disinfested maize (var. Shaba) in 900 ml glass jars to give the contents 5, 10, 20, and 40 g/kg, respectively. Each jar was then closed with a perforated metal lid. The powder extract plus grain was thoroughly hand mixed for 5 min. Control for each set of treatments consisted of grain containing no plant material. Each treatment was repeated 3 times. A group of 20 adult *S. zeamais* of mixed sex, aged 2–3 weeks, was added into the jars containing the treated or untreated grains. Adult mortality was recorded 14 days after treatment

Population increase and Damage

The two middle contents 10 and 20 g/kg as applied in the previous section of the shade-dried powder with 1-mm particle size from the four plant species for 100 g grain were prepared as described earlier. A group of 25 (2-3 weeks old) adult *S. zeamais* of mixed sex was introduced into each jar containing treated or untreated grain. Control for each set of treatments consisted of grain without plant material. Each treatment was repeated 3 times. After 3 months, the number of live insects was determined for each jar. Grain damage was determined by randomly selecting 100 grains from each jar and the number of damaged (grains with characteristic holes) and undamaged (without holes) grains were counted and weighed (Nukenine et al., 2010a). Another damage parameter, Weevil Perforation Index (WPI), was estimated as follows (Fatope et al., 1995):

WPI = (% treated maize grains perforated)/(% control maize grains perforated)

WPI > 50: negative protectant of plant material tested (i.e. enhancement of infestation by the weevil)

WPI < 50: positive protectant (i.e. prevention of infestation by the weevil).

Drying regime and particle size

The powders of *P. glandulosus* and *S. araliacea* from the sun- and shade-dried leaves with particle size of 0.2 mm and 1 mm were used for this bioassay. Similar treatments like for the section on “Adult mortality” above was applied here. For drying regime, sun- and shade-dried leaves with particle size 0.2 mm were considered for the two plant species. Powders with particle size 0.2 and 1 mm from the shade-dried leaves of the two plants were used. The different powder contents were mixed with maize grains as described previously. A group of 20 (2-3 weeks old) adult *S. zeamais* of mixed sex was introduced into each jar containing treated or untreated grain. Control for each set of treatments consisted of grain without plant material. Each treatment was repeated 3 times. Adult mortality was recorded 30 days after treatment.

Statistical analysis

Percentage mortality data of *S. zeamais* adults were not corrected for control mortality, because mortality in the control treatment was ≤ 2% (Abbott, 1925). Data on % cumulative mortality and % grain damage were arcsine-transformed [square root(x/100)] and the number of *S. zeamais* adults was log-transformed (x + 1). The transformed data were subjected to the ANOVA procedure using the statistical analysis system (SAS Institute 2003). Tukey studentized (HSD) test (P = 0.05) was applied for mean separation.

RESULTS

Adult mortality

Mortality of *S. zeamais* was affected by powder content for treatments with *A. indica* and *P. glandulosus*, but not *A. araliacea* and *A. senegalensis* (Table 1). Control mortality was ≤2.0% and differed from all the treatments for *A. indica* and *P. glandulosus*, but with treatments ≥20 g/kg for *S. araliacea*. The mortality caused to *S. zeamais* varied among the plant species and decreased in the following order: *P. glandulosus* > *A. indica* >> *A. senegalensis* = *S. araliacea*. The highest tested content (40 g/kg) of the leaf powder from *P. glandulosus*, *A. indica*, *S. araliacea* and *A. senegalensis* achieved 83%, 38%, 7% and 5% mortality of *S. zeamais*, respectively.

Population increase and grain damage

The rate of increase of the population of *S. zeamais* was greatly reduced by the plant powders, except for *A. senegalensis* (Table 2), especially for the higher content (40 g/kg). However, the lower content (20 g/kg) of *A. indica* and *S. araliacea* reduced the rate of population increase of *S. zeamais* 10- and 2-fold, respectively. The controls and the samples treated with *P. glandulosus* (20 g/kg) and *A. senegalensis* (20 and 40 g/kg) had statistically similar numbers of live weevils after three months.

All the powders significantly reduced grain damage from the weevil attack, with the samples treated with 20 or 40 g/kg of *A. indica* and *S. aralicea*, and 40 g/kg of *P. glandulosus* and *A. senegalensis* recording a smaller number of damaged grains than the controls (Table 2). However, the WPI (< 10%) showed that only *A. indica* (20 and 40 g/kg) and *P. glandulosus* (40 g/kg) were effective in preventing infestation of the maize grains by *S. zeamais*.

Drying regime and particle size

Table 3 shows the percentage mortality of *S. zeamais* adults after exposure to increasing contents of powders from Shade-dried and sun-dried leaves of *P. glandulosus* and *S. araliacea* for one month. Adult mortality was dose-dependent for *P. glandulosus* but not *S. araliacea*. The mortality of *S. zeamais* was not different between the shade-dried and sun-dried leaves for all the contents of *S. araliacea* and the lower contents (5 and 10 g/kg) for *P. glandulosus* powder. At powder contents of 20 and 40 g/kg for *P. glandulosus*, the weevil mortality caused by the shade-dried powder was greater than that caused by the sun-dried powder. For these two contents, 47% vs. 12% and 68% vs. 22% mortality were achieved for the shade- and sun-dried powders of the plant, respectively.

Similarly, the adult mortality of *S. zeamais* was dose-dependent for *P. glandulosus* and not *S. araliacea* for the fine- and coarse-particle powders (Table 4). Control mortality was lower than those of the treatments with powder contents ≥20 g/kg, regardless of plant species or particle size. At higher powder contents for *P. glandulosus* (20 and 40 g/kg) and *S. araliacea* (40 g/kg), mortality caused by the fine powder to *S. zeamais* was higher compared with that caused by the coarse powder.

Table 1: Mortality of adult *Sitophilus zeamais* exposed to four plant powders for two weeks.

Content (g/kg)	Plant powder % mortality (mean ± SE)				$F_{(3,8)}$
	Azadirachta indica	*Plectranthus glandulosus*	*Steganotaenia araliacea*	*Annona senegalensis*	
0	2 ± 1.7cA	2 ± 1.7dAB	0 ± 0.0bA	0±0.0aA	0.7ns
5	13 ± 1.7bA	10 ± 0.0cAB	2 ± 1.7abB	3±1.7aAB	6.6*
10	22 ± 1.7bA	40 ± 2.9bA	3 ± 1.7abB	3±1.7aB	22.1***
20	27 ± 1.7abB	65 ± 5.8aA	5 ± 0.0aC	5±2.9aC	37.3***
40	38 ± 1.7aB	83 ± 4.4aA	5 ± 0.0aC	7±1.9aC	158.5***
$F_{(4,10)}$	34.3***	71.0***	4.3*	2.1ns	

Means in the same column followed by the same lowercase letter do not differ significantly; means in the same row followed by the same uppercase letter do not differ significantly at P<0.05 (Tukey test). Each datum represents the mean of three replicates. ns P < 0.05, * P< 0.05, *** P < 0.001.

Table 2: Population increase and damage parameters of *Sitophilus zeamais* in maize admixed with different contents of powders from four plant species and stored for three months.

Plant species	Content (g/kg)	No. of insects (mean ± S.E.)	Damaged grains (%) (mean ± S.E.)	Weevil Perforation Index (%)
Azadirachta indica	0	388 ± 17.2a	93 ± 1.5a	
	20	31 ± 9.2b	8 ± 1.2b	8.6
	40	6 ± 1.7c	3 ± 1.2c	3.2
	$F_{(2,6)}$	82.8***	437.2***	
Plectranthus glandulosus	0	344 ± 19.3a	91 ± 1.3a	
	20	221 ± 18.1a	80 ± 6.1a	87.9
	40	21 ± 3.4b	7 ± 0.3b	7.7
	$F_{(2,6)}$	2079.7***	133.4***	
Steganotaenia araliacea	0	313 ± 6.6a	89 ± 2.1a	76.4
	20	145 ± 6.8b	68 ± 7.0b	60.7
	40	183.7± 7.7c	54 ± 4.5b	
	$F_{(2,6)}$	107.2***	14.1**	
Annona senegalensis	0	274 ± 7.8a	87 ± 1.9a	
	20	259 ± 51.4a	81 ± 0.6ab	93.1
	40	257 ± 17.0a	77 ± 2.4b	88.5
	$F_{(2,6)}$	0.15ns	7.9*	

Means in the same column followed by the same letter do not differ significantly at P < 0.05 (Tukey test). Each datum represents the mean of three replicates. ns P < 0.05, * P < 0.05, *** P < 0.001.

Table 3: Mortality of adult *Sitophilus zeamais* exposed to powders of *Plectranthus glandulosus* and *Steganotaenia araliacea* from shade- and sun-dried leaves for one month.

Plant species	Content (g/kg)	Drying regime % Mortality (Mean ± S.E.)		*t*-value
		Shade	Sun	
P. glandulosus	0	0d	0b	
	5	13 ± 3.3c	3 ± 2.9b	2.9ns
	10	15 ± 2.9c	8 ± 5.8ab	1.5ns
	20	47 ± 1.7b	12 ± 1.7ab	14.8***
	40	68 ± 3.3a	22 ± 4.4a	8.4**
	$F_{(4,10)}$	128.2***	7.1**	
S. araliacea	0	0b	0b	
	5	5 ± 2.9ab	7 ± 1.7a	-0.5ns
	10	8 ± 1.7ab	7 ± 1.7a	0.7ns
	20	15 ± 2.9a	8 ± 1.7a	2.0ns
	40	18 ± 3.3a	12 ± 1.7a	1.8ns
	$F_{(4,10)}$	5.9*	24.0***	

Means in the same column followed by the same letter do not differ significantly at P < 0.05 (Tukey test). Each datum represents the mean of three replicates. ns P < 0.05, * P < 0.05, ** P < 0.01, *** P < 0.001.

Table 4: Mortality of adult *Sitophilus zeamais* exposed to powdered leaves of *Plectranthus glandulosus* and *Steganotaenia araliacea* with fine and coarse particles for one month.

Plant species	Content (g/kg)	Particle size % Mortality (mean ± S.E.)		*t*-value
		Fine (0.2 mm)	Coarse (1.0 mm)	
P. glandulosus	0	0c	0	
	5	7 ± 3.3bc	13 ± 1.7c	-1.8ns
	10	18 ± 1.7b	14 ± 1.7c	2.1ns
	20	62 ± 4.4a	23 ± 1.7b	8.1**
	40	68 ± 4.4a	38 ± 3.3a	5.4**
	$F_{(4,10)}$	55.4***	30.8***	
S. araliacea	0	0c	0b	
	5	10 ± 1.9b	12 ± 1.7a	-0.5ns
	10	17 ± 3.3ab	15 ± 2.9a	0.4ns
	20	15 ± 2.9b	15 ± 2.9a	0.0ns
	40	30 ± 2.9a	18 ± 1.7a	3.5*
	$F_{(4,10)}$	106.5***	10.6**	

Means in the same column followed by the same letter do not differ significantly at P<0.05 (Tukey test). Each datum represents the mean of three replicates. ns P < 0.05, * P< 0.05, ** P < 0.01, *** P < 0.001.

DISCUSSION

Our investigations showed a high insecticidal efficacy of *P. glandulosus* powder against adult *S. zeamais*, but much lower efficacy for *A. indica* powder and practically no activity for *A. araliacea* and *A. senegalensis*, within 14-d exposure period. Koona and Njoya (2004) contented that powdered dried leaves of plants can cause death through desiccation of insects or through occlusion of their spiracles, thereby preventing respiration via the tracheal system. These mechanisms are not in line with the findings of the present study, because even at the highest powder content of 40 g/kg, *S. araliacea* and *A. senegalensis* recorded <8% and *A. indica* only 38% mortality of the weevil. *P. glandulosus* which is more aromatic than the other plants caused a much higher mortality of 83% to *S. zeamais* within the 14-d exposure period. Furthermore, Golob (1997) demonstrated that dusts are only effective in killing insects through desiccation when the particles are very small. The particle size in the present study was large (1 mm). It therefore appears more plausible to attribute the toxicity of the powders to their volatile components which are dominated by monoterpenoids in the case of *P. glandulosus*, *S. araliacea* and *A. senegalensis* (Jirovetz et al., 2002; Nukenine et al., 2007). Weaver et al. (1995) attributed the very significant insecticidal activity of the leaf powders from two aromatic plants (*Artemesia tridentata* (Nutt.) and *Monarda fistulosa* L.) against *Zabrotes subfasciatus* (Boheman) (Coleoptera: Bruchidae) to the liberation of highly volatile terpenoid compounds by powdering. The leaf essential oil from *P. glandulosus* collected in Ngaoundere, Cameroon in July 2004 was rich in cis-piperitone (19.5%), fenchone (18.3%), piperitone oxide (17.9%), piperitone (8.9%) and terpinolene (8.2%) (Nukenine et al., 2007). Park et al. (2003) found terpinolene to be highly toxic to *Sitophilus oryzae* (L.) and *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae). Nukenine et al. (2010b) also demonstrated high toxicity of fenchone on coated maize grains to *S. zeamais*. Concerning the mode of action of monoterpenes, Ryan and Byrne (1988) suggested that the toxic effect may be attributed to reversible competitive inhibition of acetylcholinesterase by occupation of the hydrophobe site of the enzyme’s active centre.

Under fixed laboratory condition of 25 °C and 60-65% r.h., powdered leaves (500 µm) of *P. glandulosus* collected in October 2004 at Ngaoundere and applied at the rate of 40 g/kg on grains caused 88% mortality to *S. zeamais* within 14-d, which accords with the 83% mortality recorded in the present study under uncontrolled laboratory conditions (Nukenine et al., 2010a). In a related study carried out under same conditions, leaf powders of *P. glandulosus* and *S. araliacea* collected in July 2004, achieved respectively 81% and 30% mortality of *S. zeamais* within 8 days, and 100% and 65% within 16 days (Nukenine et al., 2007). This indicates a better activity of the two plant powders than in the present study where leaf collection was done in November 2006. This suggests that *P. glandulosus* collected earlier in the season may be richer in volatile terpenoids compared to that collected later in the season. It suggests also that the insecticidal activity of *S. araliacea* may be affected more by environmental conditions than that of *P. glandulosus*. There is thus the need of testing the insecticidal activity of botanical powders under different environmental conditions in order to validate their use in stored grain protection. Nonetheless, the results from studies that assess the efficacy of botanicals under uncontrolled laboratory conditions would be more meaningful in the protection of grains in subsistence agriculture, where grains are stored under unaltered environmental conditions.

The low mortality of the weevil recorded by *A. indica* seed powder within 14-d was not surprising because its constituents, including the dominant azadirachtin, a tetranotriterpenoid limonoid, possess antifeedant, repellant, growth disrupting and larvicidal properties against a large number of pests (Schmutterer, 1990; Aerts and Mordue, 1997; Mathur, 2013). The antifeedant mechanism takes a longer time to cause high or complete mortality to insects, and it is thought to be the dominant mode of action in the present study. This antifeedant mechanism and the other modes of action of *A. indica* powder stated above gain further support from the results of our study on population increase and grain damage, where the plant was by far the most effective. Indeed, *A. indica* powder at the rates of 20 g/kg and 40 g/kg reduced the rate of *S. zeamais* population increase 12- and 65-fold, respectively, confirming its potential as a grain protectant against insects. The grain protectant ability of *A. indica* seed powder is re-enforced by the very low percentage damaged grains and WPI recorded by the grains treated with this powder. *A. indica* seed powder at the rate of 15 g/kg was effective in protecting bean seeds against the infestation of *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) and *Z. fasciatus* under farm conditions (Paul et al., 2009). This corroborates the results of this study considering that *A. indica* seed powder at 20 g/kg greatly protected maize grains against the infestation of *S. zeamais*.

Azadirachta indica seed powder is rich in oil and leaves the treated grains with a pungent smell and off-taste, which are difficult to remove. The aromatic *P. glandulosus* leaf powder is easy to remove from the grains and leaves very little smell and only slightly altered taste to the grains which could be washed away with less effort. Farmers in Tanzania who protected their grains with *Chenopodium ambrosiodes* L. (Chenopodiaceae) complained about the pungent smell and bad taste of the cooked beans (Paul et al., 2009). *P. glandulosus* leaf powder therefore stands a good chance for adoption in the protection of both food and seed grains against insect infestation, while *A. indica* seed powder would be more attractive for the protection of seed grains and less adopted for food grains.

The higher efficacy of fine-particle-powder from *P. glandulosus* against adult *S. zeamais* compared with the coarse-particle-powder was not surprising because smaller particle size implies better liberation of volatile insecticidal terpeinoids compounds from the leaves (Weaver et al., 1995). Asawalam and Emosairue (2006) recorded also better efficacy of smaller particles (0.6 mm) of *P. guineense* powder against *S. zeamais* compared to the larger particles (2 mm). The smaller particle powder of *P. glandulosus* could also be effective against *S. zeamais* through dessication. Golob (1997) demonstrated that dusts are only effective in killing insects through desiccation when the particle size is very small. Exposure of botanicals to sunlight may lead to photo-degradation and thermo-degradation (Jenkins et al., 2003; Ilboudo et al., 2010). This is thought to be the major reason why the powders from sun-dried *P. glandulosus* leaves were less effective against *S. zeamais* than that from the shade-dried leaves.

Based on the good efficacy of powders from *P. glandulosus* leaves and *A. indica* seeds in protecting maize against the infestation of the noxious *S. zeamais* indicated in the present study and because they are available, easy to prepare and environmentally safe and friendly, a wide use of these botanicals is recommended for the control of the economically important *S. zeamais*. It is also recommended to use powders from shade-dried plant parts, with smaller particles (0.2 mm) rather than sun-dried parts, with larger particles.

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