

Bioactivity of Selected Plant Powders against *Prostephanus truncatus* (Coleoptera: Bostrichidae) in Stored Maize Grains

FRIDAH CHEBET¹, AROP L. DENG², JOSHUA O. OGENDO¹, ALICE W. KAMAU¹ and PHILIP K. BETT²

¹Department of Crops, Horticulture and Soils and ²Department of Biological Sciences,
Egerton University, Egerton, Kenya

Abstract

CHEBET F., DENG A.L., OGENDO J.O., KAMAU A.W., BETT P.K. (2013): **Bioactivity of selected plant powders against *Prostephanus truncatus* (Coleoptera: Bostrichidae) in stored maize grains.** Plant Protect. Sci., **49**: 34–43.

Crude powders of *Azadirachta indica*, *Lantana camara*, and *Tephrosia vogelii*, each at six concentrations (0.0, 2.0, 4.0, 6.0, 8.0, and 10% w/w), and Actellic Super™ 2% dust were evaluated for repellence anti-feeding and toxicity to adult *Prostephanus truncatus*. Treatments were laid out in a completely randomised design with four replicates. Results showed that powders were strongly repellent (PR values 73.0–90.0%) and caused 46.2–52.2 and 69.7–85.6% reductions in grain damage and F₁ progeny, respectively. Results showed that powders were weakly toxic to *P. truncatus* causing 40% kill 21 days after treatment compared to 100% kill by Actellic Super™ 2% dust 5 DAT. The findings are discussed in the context of their relevance for integrated pest management options in smallholder agriculture.

Keywords: *Azadirachta indica*; *Lantana camara*; *Tephrosia vogelii*; botanicals

Insects cause substantial quantitative and qualitative pre- and post-harvest losses varying in magnitude from 10% to 100% in tropical countries (MUGISHA-KAMATENESI *et al.* 2008) and in Kenya, 10–60% losses of stored cereal and legume grains (OGENDO *et al.* 2004). These substantial losses are caused by *Sitophilus* spp. and *Sitotroga cerealella* on cereals, *Acanthoscelides* and *Callosobruchus* on legumes (DOBIE 1991) and more damage in cereals is also caused by tenebrionid beetles and newly introduced *Prostephanus truncatus* in stored cereals and cassava. *P. truncatus* (Horn), being an introduced species and spreading rapidly, has become a major problem in most areas that produce maize and cassava (OGEMAH 2003).

In the past few decades the application of synthetic pesticides to control pests of durable stored food products including *P. truncatus* has been the standard practice. However, with evidence that the use of synthetic insecticides poses possible health hazards to warm-blooded animals, risk of environmental pollution, development of resist-

ance by insects and pest resurgence, requirements for effective, affordable and eco-friendly control options have become crucial (BANWO & ADAMU 2003; RAJENDRAN & SRIRANJINI 2008). Botanical pesticides, despite having different active constituents and modes of action are target-specific, relatively safe, affordable and readily available. Hence, the readily available botanical pesticide technology for pest management in smallholder agriculture is a viable alternative option.

The insecticidal activity of several plant essential oils, powders and other extracts has been evaluated against several insect pests of cereals and legumes and found to have contact toxicity (ASAWALAM *et al.* 2006; OGENDO *et al.* 2008), repellence (KÉITA *et al.* 2001; ROSMAN *et al.* 2007), fumigant toxicity (LEE *et al.* 2003; RAJENDRAN & MURILADHARAN 2005), anti-feedant (SAXENA *et al.* 1992; OGEMAH 2003) effects. OGENDO *et al.* (2008) reported that essential oils extracted from aerial parts of *Ocimum americanum*, *Lantana camara* and *Tephrosia vogelii* and monoterpene

Supported by the African Institute for Capacity Development (AICAD).

constituent, eugenol, had concentration, exposure time, species (plant and insect) and plant part-dependent instant and residual repellent potency against adult *Tribolium castaneum*, *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Callosobruchus chinensis*. Similarly, *L. camara* has been reported to have anti-oviposition and growth regulating effects against field and storage insect pests (SAXENA *et al.* 1992). Plants have been found to contain triterpenoids, iridoid glycosides, some of which may be responsible for the observed insecticidal properties (SHARMA *et al.* 1995).

However, the larger grain borer, *P. truncatus*, has received little attention in the area of rationalised use of botanical pesticides, especially of the use of extracts of *Azadirachta indica*, *Lantana camara*, and *Tephrosia vogelii* for the stored product insect control. The purpose of the present study was to evaluate the repellent, feeding deterrence and contact toxicity effects of plant powders of *A. indica*, *L. camara*, and *T. vogelii* on *P. truncatus* with the hope of finding an effective, affordable and environmentally safe product for use by subsistence farmers.

MATERIAL AND METHODS

Mass rearing of *P. truncatus*. Approximately 250 unsexed adult *P. truncatus* were introduced into 1-l glass jars containing 500 g of Katumani composite B maize grain samples and kept at 25–30°C and 65–70% R.H. and 12:12 h (light:darkness). The insects were allowed to lay eggs for 14 days (OGEMAH 2003). The jars were covered using plastic stoppers reinforced on the inside with 0.5 mm wire gauze to prevent the insects from chewing through them. The beetles and flour frass were separated from the treated grains by repeated gentle sieving through layering of 3 mm and 1 mm mesh sieves, respectively. The grains were retained by the 3 mm sieve whereas the beetles and flour frass were retained in the 1 mm sieve and holding pan, respectively. Those that did not come out during the sieving were forced out by probing with a plastic fibre. The grains and flour frass were then returned into the jars and kept at 65–70% R.H. until the adults emerged after 25–35 days. These adults were also obtained by sieving as described above.

Collection and preparation of test plant powders. Fresh samples (mixture of leaves, in-

florescence and succulent stems) of *L. camara* L., *T. vogelii* Hook, and *A. indica* A. Juss were collected from Kabarak, Rongai District (latitude 0°11'N; longitude 35°59'E; altitude 2110 m a.s.l.), Egerton University's Tatton Farm, Njoro (latitude 0°13'–1°10'N; longitude 35°28'–35°36'E; altitude 2250 m a.s.l.), and Marigat, Baringo District (latitude 0°28'N; longitude 35°58'E; altitude 1062 m a.s.l.) in clearly labelled manila bags and transported to the experimental site within 24 hours. The fresh plant samples were dried under shade at ambient temperatures (18–28°C) for 14 days and further oven dried at 35°C for 48 h (WAMBUA *et al.* 2011). Dry samples were ground into fine powders using an electric laboratory hammer mill. The powders were then stored in air-tight glass jars in a cool place away from sunlight.

Laboratory bioassays

Repellence studies (choice bioassay). A bioassay consisting of a circular flat-bottomed plastic basin (45 cm in diameter by 30 cm in height) whose base was divided into four equal portions as described by OGENDO *et al.* (2004) was used to evaluate the repellence of crude *A. indica*, *T. vogelii*, and *L. camara* powders against adult *P. truncatus*. Each plant powder was evaluated at five rates (0, 2, 5, 7, and 10% w/w) and Actellic Super™ 2% dust included as a positive control. Alternate treated and untreated maize grains (100 g) were placed equidistantly from the centre of the circular base. The treatments were arranged in a Completely Randomised Design (CRD) with 4 replicates per concentration including a no-choice control with untreated maize in all four portions. The top of the basin was covered with a fine wire mesh to prevent the insects from escaping. For each treatment, 20 adult *P. truncatus* (5–10 days) were released at the centre of the basin. The total number of insects that settled on the control and the treated grains was recorded after 1, 12, and 24 h of exposure. Percent repellence (PR) was calculated and interpreted as described by TALUKDER and HOWSE (1993) as follows;

$$PR = 2 (C - 50) \quad (1)$$

where: C – percent of insects that settled on the untreated grains

Feeding deterrence (grain damage) studies. Maize grain samples (100 g) were weighed and

put into 500 g glass jars and separately treated with *A. indica*, *T. vogelii*, and *L. camara* powders. Each plant powder was evaluated at six rates (0, 2.0, 4.0, 6.0, 8.0, and 10% w/w) and kept at 25–30°C and 65–70% R.H. Thirty unsexed adult *P. truncatus* (5–10 days) were introduced into the treated grains and allowed to feed. After 7 and 21 days, insects were removed and the amount of frass (flour) produced was determined by sieving the samples and weighing the resultant frass (flour). Percent grain damage was computed according to DOBIE (1991) as follows:

$$\text{Weight loss (\%)} = \frac{(UNd - DNu)}{U(Nd + Nu)} \times 100 \quad (2)$$

where:

U – weight of undamaged grains

D – weight of insect-damaged grains

Nu – number of undamaged grains

Nd – number of insect-damaged grains

Contact toxicity and F_1 progeny studies. Maize grains (100 g) were weighed into 250 ml glass jars and admixed with *A. indica*, *T. vogelii*, and *L. camara*, powders at six different dosages (0, 2.0, 4.0, 6.0, 8.0 and 10% w/w). Maize treated with synthetic insecticide Actellic Super™ 2% dust (0.05% w/w) was used as positive control. Twenty (N_T) unsexed *P. truncatus* adult beetles (5–10 days old) were placed into each experimental jar. A CRD with 4 replicates per treatment was used. The top of each jar was covered using plastic stoppers reinforced on the inside with 0.5 mm wire gauze to prevent the insects from chewing through them. The experimental units were kept at 25–30°C and 65–70% R.H. The number of dead (N_D) insects in each jar was recorded 1, 3, 5, 7, 14 and 21 days after treatment (DAT). The adult beetles were removed from the grains in experimental jars 21 DAT and the grains returned into the jar and kept for F_1 progeny counts. The number of newly emerged adult F_1 progeny insects was recorded 28, 35, and 42 DAT. The percent reduction in adult emergence or reproduction inhibition rate (IR %) was computed according to TAPONDJOU *et al.* (2002) as shown in Eq. 1:

$$\text{Reproduction inhibition rate (\%)} = \frac{(C_N - T_N)}{C_N} \times 100 \quad (3)$$

where:

C_N – number of newly emerged adult insects in the untreated control

T_N – number of newly emerged adult insects in the treated grains

Data analysis. Data on corrected percent mortality and repellence were first homogenised using log-transformation to correct for heterogeneity of treatment variance (GOMEZ & GOMEZ 1984) before being subjected to ANOVA and repeated measures analysis using Statistical Analysis System and means were separated using Tukey's HSD-test (SAS release 8.02, 2001; WAMBUA *et al.* 2011). Data obtained from various concentration-response bioassays (contact toxicity and repellence) were further log-transformed before being subjected to probit regression analysis using EPA Probit Analysis Program version 1.4 and LC_{50}/RC_{75} values and corresponding 95% fiducial limits were obtained from derived regression equations. The LC_{50} values in a column were considered significantly different when 95% fiducial limits did not overlap. The RC_{75} represents the concentration that repels 75% of test insects.

RESULTS

Repellence studies (choice bioassay)

Percent repellence (PR) results of adult *P. truncatus* to maize grains treated with varying crude powder concentrations of *L. camara*, *T. vogelii*, and *A. indica* are presented (Figure 1, Table 1). The magnitude of repellence of adult *P. truncatus* insects was significantly ($P < 0.05$) influenced by plant species, concentration of powder applied, exposure time and corresponding factor interactions. The test plant powders exhibited clear dose-dependent increasing PR values over the 24 h exposure period. At 7.0–10.0% w/w and 24 h exposure, maize grains treated with crude *T. vogelii* and *A. indica* powders equally had the highest PR values of 90 and 88%, respectively, whereas the other plant powder, *L. camara* caused 73% repellence of adult *P. truncatus* insects. The synthetic insecticide, Actellic Super™ 2% dust, at 0.05% w/w and 24 h exposure, was the most repellant against adult *P. truncatus* with a PR value of 95.0% whereas the untreated maize grains (negative control) had the test insects well distributed in the choice bioassay (PR value 0).

Feeding deterrence (grain damage) studies

Results of feeding deterrence expressed as percent damage and weight of frass (flour) arising

Table 1. Percent repellence (mean \pm SE, $n = 4$) of adult *P. truncatus* to varying exposure time and concentrations of *L. camara*, *T. vogelii*, and *A. indica* crude powders in a choice bioassay

Treatments	Concentration (% w/w)	Exposure time (h)		
		1	12	24
Actellic Super 0.02%	0.05	95.0 \pm 1.4	95.0 \pm 1.4	95.0 \pm 1.4
<i>L. camara</i>	2.0	20.0 \pm 9.1	33.0 \pm 4.8	45.0 \pm 6.4
	5.0	35.0 \pm 8.7	38.0 \pm 7.5	48.0 \pm 8.5
	7.0	60.0 \pm 7.1	65.0 \pm 5.0	68.0 \pm 6.8
	10.0	70.0 \pm 4.0	70.0 \pm 4.8	73.0 \pm 6.8
	RC ₇₅	12.71	14.57	11.65
<i>T. vogelii</i>	2.0	50.0 \pm 4.1	55.0 \pm 5.0	73.0 \pm 2.5
	5.0	55.0 \pm 2.8	60.0 \pm 5.7	80.0 \pm 0.0
	7.0	60.0 \pm 4.1	68.0 \pm 4.8	85.0 \pm 2.9
	10.0	67.5 \pm 4.8	73.0 \pm 4.9	90.0 \pm 0.0
	RC ₇₅	24.03	11.96	2.27
<i>A. indica</i>	2.0	40.0 \pm 4.0	55.0 \pm 2.9	75.0 \pm 5.0
	5.0	73.0 \pm 6.8	75.0 \pm 5.0	80.0 \pm 4.1
	7.0	70.0 \pm 3.9	85.0 \pm 2.9	83.0 \pm 2.9
	10.0	78.0 \pm 6.8	82.5 \pm 3.7	88.0 \pm 4.8
	RC ₇₅	7.09	4.79	2.27

Means in a column followed by different letters are significantly different at $\alpha = 0.05$ by *LSD*; RC₇₅ refers to the concentration (% w/w) that repels 75% of the test insects using Probit Regression Analysis

from adult *P. truncatus* insect feeding on maize grains treated with varying concentrations of *L. camara*, *T. vogelii*, and *A. indica* crude powders are presented (Figure 2, Table 2). The percent of grain damage and amount of frass produced due to adult *P. truncatus* were significantly ($P < 0.05$) influenced by plant, concentration applied and plant by concentration interaction effects. A clearly discernible dose-dependent reduction in percent grain damage was observed with *T. vogelii*

and *A. indica* powders equally causing the highest suppression (52.2%) of insect damage when benchmarked against the untreated control that recorded the highest damage. Crude *L. camara* powder treatment produced a 46.2% reduction in maize grain damage. Maize grains treated with synthetic insecticide, Actellic SuperTM dust, recorded no insect feeding (= no damage) due to the high toxicity of insecticide to the test insects. The overall observed percent damage, in order of a

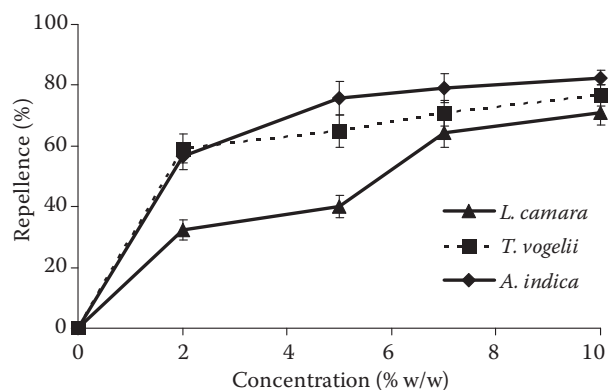


Figure 1. Percent repellence (mean \pm SE, $n = 4$) after 24 h exposure of *P. truncatus* to varying concentrations of *L. camara*, *T. vogelii*, and *A. indica* crude powders

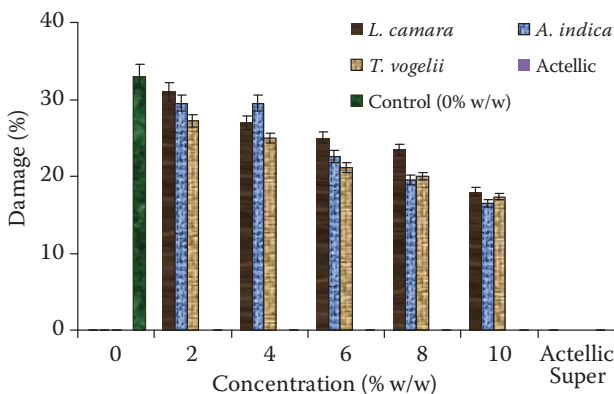


Figure 2. Percent damage (mean \pm SE, $n = 4$) by adult *P. truncatus* to maize grains treated with varying concentrations of *L. camara*, *T. vogelii*, and *A. indica* crude powders

Table 2. Effect of treating maize grain with crude powders of *L. camara*, *T. vogelii*, and *A. indica* on adult *P. truncatus* F₁ progeny counts 42 days after treatment

Treatments	Concentration (% w/w)	F ₁ progeny counts (mean ± SD)	F ₁ reduction (%) ^a
Untreated control	0.0	52 ± 12.33 ^a	0.0
Actellic Super TM 0.02%	0.05	0.00 ± 0.00 ^e	100.00
<i>L. camara</i>	2.0	26.5 ± 6.4 ^c	49.00
	4.0	26.25 ± 6.70 ^c	49.52
	6.0	23.25 ± 6.38 ^{cd}	55.30
	8.0	20.25 ± 4.93 ^d	61.06
	10.0	14.75 ± 4.55 ^e	71.63
	<i>LSD</i> _{0.05}	1.16	
<i>T. vogelii</i>	2.0	41.05 ± 9.90 ^b	21.06
	4.0	30.75 ± 7.60 ^c	40.87
	6.0	28 ± 7.10 ^c	46.15
	8.0	20 ± 5.37 ^d	61.54
	10.0	15.75 ± 4.33 ^e	69.71
	<i>LSD</i> _{0.05}	1.16	
<i>A. indica</i>	2.0	33.5 ± 8.11 ^b	33.58
	4.0	25.75 ± 6.63 ^c	50.48
	6.0	18.5 ± 4.41 ^d	64.42
	8.0	13.5 ± 3.30 ^{cd}	74.04
	10.0	7.5 ± 1.80 ^e	85.58
	<i>LSD</i> _{0.05}	1.16	

Means in a column followed by different letters are significantly different at $\alpha = 0.05$ by *LSD*; ^apercent reduction in F₁ progeny counts with untreated control as reference treatment

decreasing level of damage, was untreated control (33.5%), *T. vogelii* and *A. indica* (17.5%), *L. camara* (15.5%) and Actellic SuperTM dust (0.0%).

Similar result trends were recorded for the weight of frass resulting from adult *P. truncatus* feeding on maize grains treated with varying concentrations of the three test botanical powders (Table 3). At 10.0% (w/w) and 42 days after treatment, maize grains treated with *T. vogelii* and *A. indica* powders produced the least amount of frass (1.50–1.55 g/100 g) compared to 2.42 g/100 g in *L. camara* treated grains (Table 3). The untreated maize grains produced 2 and 7 times more frass than *L. camara* and *T. vogelii*/*A. indica*-treated grains.

Contact toxicity and F₁ progeny studies

The results of adult *P. truncatus* mortality and F₁ progeny counts are presented (Figures 3 and 4, Table 2). Results showed that the toxicity of crude

powders was significantly ($P < 0.05$) influenced by plant, concentration applied, contact duration (days) and corresponding factor interactions. Although the botanical powders produced clear dose-dependent toxicity to adult *P. truncatus*, the end-point mortalities were less than 40% after 21 days of contact with treated maize grains (Figure 3). The concentration of powder applied and duration of contact (days) significantly influenced the percent mortality of adult *P. truncatus* insects. Probit regression analysis of dose-response produced LC₅₀ values of 17.3, 17.6, and 47.0% (w/w) for crude powders of *L. camara*, *T. vogelii*, and *A. indica*, respectively. The positive control, Actellic SuperTM 0.02% dust, at 0.05% (w/w), caused the highest mortality (100%) after 5 days of contact. Thus, the crude powders of *L. camara*, *T. vogelii*, and *A. indica* were inferior compared to the positive control.

The adult *P. truncatus* F₁ progeny counts in grains treated with crude botanical powders were

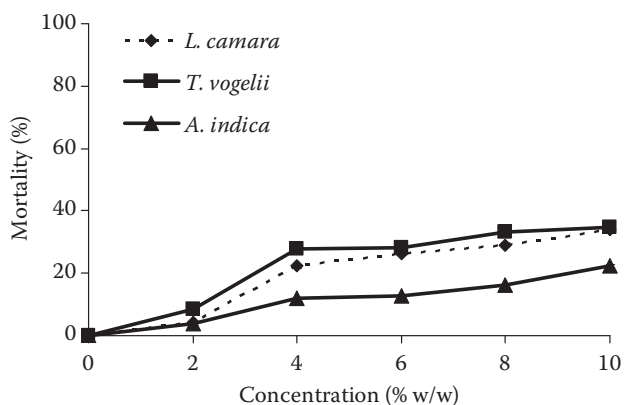


Figure 3. Percent mortality (mean \pm SE, $n = 4$) of *P. truncatus* after 21-day contact with varying concentrations of *L. camara*, *T. vogelii*, and *A. indica* crude powders

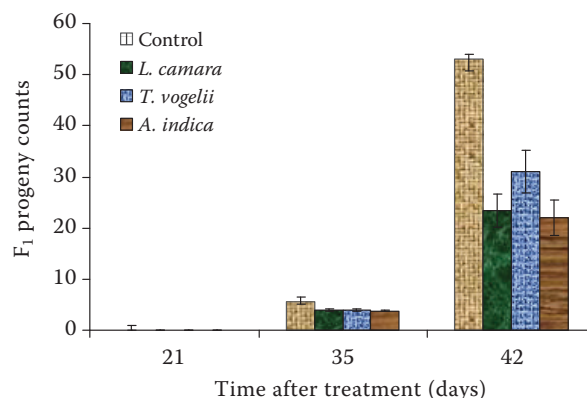


Figure 4. F_1 progeny counts (mean \pm SE, $n = 4$) of adult *P. truncatus* emergence in maize grains treated with *L. camara*, *T. vogelii*, and *A. indica* crude powders

significantly ($P < 0.05$) affected by the plant source, concentration applied and plant by concentration effects. Results showed clear dose-dependent reductions in the adult *P. truncatus* F_1 progeny counts (Figure 4 and Table 3). At the highest concentration (10.0% w/w), crude powders of *L. camara*, *T. vo-*

gelii, and *A. indica* reduced the F_1 progeny counts by 71.6, 69.7 and 85.6%, respectively, compared to the untreated control. Synthetic insecticide, Actellic Super™ 2% dust, at 0.05% (w/w), caused the total inhibition (100%) of adult *P. truncatus* F_1 progeny emergence.

Table 3. Weight of frass (mean \pm SE, $n = 4$) produced by adult *P. truncatus* in maize grains treated with varying concentrations of *L. camara*, *T. vogelii*, and *A. indica* crude powders (in g/100 g)

Treatments	Concentration (% w/w)	Contact duration (days)	
		21	42
Untreated control	0.0	1.75 \pm 0.25	4.80 \pm 0.45
Actellic Super 0.02%	0.05	0.00 \pm 0.00	0.00 \pm 0.00
<i>L. camara</i>	2.0	0.83 \pm 0.10	3.35 \pm 0.32
	4.0	0.78 \pm 0.10	2.65 \pm 0.29
	6.0	0.76 \pm 0.09	2.60 \pm 0.24
	8.0	0.63 \pm 0.06	2.46 \pm 0.21
	10.0	0.52 \pm 0.05	2.42 \pm 0.20
<i>T. vogelii</i>	2.0	1.00 \pm 0.15	3.47 \pm 0.38
	4.0	0.79 \pm 0.07	2.30 \pm 0.24
	6.0	0.70 \pm 0.05	2.15 \pm 0.20
	8.0	0.68 \pm 0.05	2.05 \pm 0.15
	10.0	0.43 \pm 0.03	1.55 \pm 0.15
<i>A. indica</i>	2.0	0.78 \pm 0.03	2.52 \pm 0.33
	4.0	0.75 \pm 0.02	2.50 \pm 0.27
	6.0	0.70 \pm 0.03	2.47 \pm 0.25
	8.0	0.69 \pm 0.01	2.15 \pm 0.20
	10.0	0.55 \pm 0.01	1.50 \pm 0.16

Any two treatment means in a column whose standard errors do not overlap are significantly different at $\alpha = 0.05$ by *LSD*

DISCUSSION

Repellence studies (choice bioassay)

In the choice bioassay tests, all the test botanical powders exhibited strong dose- and exposure time-dependent repellence against adult stages of *P. truncatus* insects. Grains treated with crude powders of *T. vogelii* and *A. indica* were equally the most repellent (PR values: 88–90%) against adult *P. truncatus* followed by *L. camara* (PR 73%). These results concur with recent local studies in which crude powders of *L. camara* and *T. vogelii*, at 10% w/w and 24 h exposure, produced moderate to strong repellence against adult *S. zeamais* with PR values of 62.5 and 87.5%, respectively (OGENDO *et al.* 2003). The fact that all powder treatments produced PR values of > 70% is a welcome scientific development based on the promise it holds for the rationalised use of botanical pesticides for long-term protection of stored durable agricultural products, such as maize grains, against the LGB and other stored-product insect pests. The observed repellent activity could partly be attributed to the presence of volatile constituents such as monoterpenes and sesquiterpenes which are well-known repellents of phytophagous (biting) insects by acting in the vapour form on the olfactory receptors (MOORE & LENGLET 2004; DEBBOUN *et al.* 2007; WANG *et al.* 2008). The results from this study showed clearly that botanicals exhibited contact-repellent properties against *P. truncatus* and that the test insects made oriented movements away from treated grains to get acceptable food as manifested in the alternate treated-untreated bioassay system (DETHIER *et al.* 1960). It implicitly emerges from the above arguments that volatile terpenoid constituents contribute to the repellence principle exhibited by crude powders against the LGB. The fact that various plant products such as live plants, fresh and smoke are successful cases of repellents against biting insects makes the potential of *L. camara*, *T. vogelii*, and *A. indica* powders as repellents against insect pests of stored products more promising. Aromatic plants can be used to develop alternative technologies to reduce postharvest losses of staples in tropical agriculture. Since aromatic plants have long been used in daily life as insect repellents, they are generally regarded as safe and ecosocio-friendly in contrast to synthetic pesticides.

Feeding deterrence (grain damage) studies

From the results of our study the crude plant powders exhibited strong dose- and contact duration-dependent feeding deterrence as expressed in terms of reduced grain loss/damage (%) and amount of frass produced due to insect feeding activity. As observed in the choice bioassay, grains admixed with crude powders of *T. vogelii* and *A. indica* were equally the most deterrent reducing adult *P. truncatus* grain damage by 52.2% as referenced against the untreated control whereas *L. camara* powder produced 46.2% reduction.

Grain injury is usually measured by the count-and-loss method, which yields two alternative measures, percentage kernels damaged and percent weight loss (BOXALL 1986). In the present study percent damage of seeds was used and amount of flour produced to represent the weight loss indirectly. In the grain damage test, the amount of flour produced by *P. truncatus* decreased with an increase in the concentration of plant powders applied. The antifeedant property of any plant material would depend on active constituents of plant material. Based on previous studies, much of the antifeedant can be attributed to azadirachtin, which is known to be an important antifeedant compound in neem products (BUTTERWORTH & MORGAN 1968; REMBOLD 1995; OGEMAH 2003). Azadirachtin has been shown to stimulate the deterrent neurones and to inhibit phagostimulatory neurones in the chemoreceptor cells for various insects (BLANEY & SIMMONDS 1990). The *T. vogelii* leaves and seeds have also been reported to contain rotenoids (rotenones, tephrosin, daguelin) known to be feeding deterrents (ISMAN 2007; ADABAYO *et al.* 2007; OGENDO *et al.* 2008). Therefore, the antifeedant properties in crude powders obtained from these plants could possibly be attributed to the presence of the above chemical constituents.

The results of this study are also comparable to those of other researchers who observed that storage insect pests cause 10–100% losses (OGENDO *et al.* 2004; MUGISHA-KAMATENESI *et al.* 2008) depending on insect species, storage conditions, type of stored grain. In stored grains, damage accrues at a much higher rate than the weight loss which is proportional to the market value (COMPTON *et al.* 1998), a measure of direct importance to the farmer. The destructiveness of *P. truncatus* in this study can also be explained in terms of its

behaviour. Adult tunnelling has been estimated to destroy approximately four times as much grain as larval and adult consumption (DEMIANYK & SINHA 1988), whereas in other storage pests the consumption accounts for most of the loss.

In recent grain storage adaptability studies, similar result trends were observed by KOONA *et al.* (2007) when seeds stored in jute bags impregnated with aqueous extracts of *L. camara* recorded an 80% reduction in damage by bruchid beetles over a 6-month period. The fact that all the three botanical powders achieved more than 45% reduction in damage and amount of frass produced arising from adult *P. truncatus* insect feeding holds good promise for their adoption and rationalised use for grain protection in smallholder agriculture. Our findings corroborate ALONSO-AMELOT & AVILA-NÚÑEZ (2011)'s quantitative appraisal of grain losses due to insect activity. The observed grain protection properties of crude powder treatments could partly be attributed to a modification of the physical properties of stored maize grains that reduced inter-granular air spaces thereby discouraging insect penetration, feeding, and amount of oxygen available. Based on their weak contact toxicity, the crude plant powders succeeded in inhibiting insect feeding and oviposition. In addition to any chemical principles inherent in the plant powders, the adult insect mortalities recorded were largely due to starvation. Based on previous studies, much of the anti-feeding of test botanicals could be attributed to their bioactive principles, such as azadirachtin, known for their strong feeding deterrence properties (REMBOLD 1995; OGEMAH 2003).

Contact toxicity and F₁ progeny studies

The test botanical powders have shown two distinct effects on adult *P. truncatus* through mortality and reduced F₁ progeny emergence. The results showed that crude powders of *L. camara*, *T. vogelii*, and *A. indica* had plant specific weak toxicity to adult *P. truncatus* that was significantly dependent upon the concentration of powder applied and duration of contact with treated maize grains. In the same experiments, the test botanical powders produced clear dose-dependent reductions of adult *P. truncatus* F₁ progeny counts in which maize grains treated with *L. camara*, *T. vogelii*, and *A. indica* powders recorded 71.6, 69.7, and

85.6% reductions, respectively, compared to the untreated control. The fact that all the three botanical powders, at 10% (w/w) and 21 DAT, caused only 22.8–34.0% kill (LC₅₀ values: 17.3–47.0% w/w) of adult *P. truncatus* insects does not invoke scientific excitement. However, their strong inhibitory effects on the reproductive cycle in which the F₁ progeny were reduced by 70–86% gives a glimmer of hope for use as grain protectants against larger grain borer (LGB). Similar low toxicity levels of neem and other plant powders against LGB and *S. zeamais* had earlier been reported and low efficacy attributed to the settling of powder particles at the bottom of experimental unit, a phenomenon that was observed in the present study (COBBINAH & APPIAH-KWARTENG 1989; NIBER 1994). However, our findings are significantly inferior to previous studies in which crude powders of *L. camara* and *T. vogelii*, at the same concentration and contact duration, caused 90.0 and 93.7% kill of the maize grain weevil, *Sitophilus zeamais* (OGENDO *et al.* 2003). In other similar bioassays, *A. indica* powders caused more than 50% mortality of several stored-product insect pests of maize including *P. truncatus* (SHARMA 1995; CHIRANJEEVI & SUDHARKAR 1996). The observed toxic and reproduction inhibition effects of *L. camara*, *T. vogelii*, and *A. indica* could be a result of documented bioactive chemical principles such as isoflavanoids, flavanoids, terpenoids, and azadarachtins among other compounds (BOEKE *et al.* 2004). For example RAHIM (1998) reported that azadirachtin, at 5 mg/kg grain, inhibited *Rhyzopertha dominica* (F.) F₁ progeny production by more than 98% over a 48-week storage period.

It is evident from the above results that the test botanical powders are potential protectants (repellents, antifeedants or toxicants) of stored durable agricultural products against the larger grain borer, *P. truncatus* and other coleopteran pests. The broad-spectrum bioactivity of these botanical powders coupled with their local availability and processing makes them more acceptable and cost-effective alternatives to synthetic pesticides in smallholder agriculture. Hence, these plant-based products hold good promise for inclusion in integrated pest management (IPM) strategies especially where the emphasis is on ecological and food safety.

Acknowledgements. The authors wish to thank Kenya National Agricultural Laboratories (KNAL), Kenya Agricultural Research Institute (KARI), Kiboko Centre

and Egerton University for laboratory space, supply of test insects and other forms of institutional support during the conduct of the study.

References

- ALONSO-AMELOT M.E., AVILA-NÚÑEZ J.L. (2011): Comparison of seven methods for stored cereal losses to insects for their application in rural conditions. *Journal of Stored Products Research*, **47**: 82–87.
- ADEBAYO T.A., OLANIRAM O.A., AKANBI W.B. (2007): Control of insect pests of cowpea in the field with allelochemicals from *Tephrosia vogelii* and *Petiveria alliacea* in Southern Guinea Savannah of Nigeria. *Agricultural Journal*, **2**: 365–369.
- ASAWALAM E.F., EMOSAIRUE S.O., HASSANALI A. (2006): Bioactivity of *Xylopiia aetiopica* (Dunal) A. rich essential oil constituents on maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *Electronic Journal of Environmental, Agricultural and Food Chemistry*, **5**: 1195–1204.
- BANWO O.O., ADAMU R.S. (2003): Insect pest management in African agriculture: challenges in the current millennium. *Archives of Phytopathology and Plant Protection*, **36**: 59–68.
- BLANEY W.M., SIMMONDS M.S.J. (1990): A behavioural and electrophysiological study of the role of tarsal chemoreceptors in feeding adults of *Spodoptera littoralis*, *Helionitis virescens*, and *Helicoverpa armigera*. *Journal of Insect Physiology*, **36**, 743–756.
- BOEKE S.J., BAUMGART I.R., VAN LOON J.J.A., VAN HUIS A., DICKE M., KOSSOU D.K. (2004): Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against *Callosobruchus maculatus*. *Journal of Stored Products Research*, **40**: 423–438.
- BOXALL R.A. (1986): A Critical Review of Methodology for Assessing Farm-level Grain Losses after Harvest. Tropical Development and Research Institute, London, G191.
- BUTTERWORTH J.H., MORGAN E.D. (1968): Isolation of substance that suppresses feeding in locusts. *Chemical Communications* (London): 23–24.
- CHIRANJEEVI C., SUDHAKAR T.R. (1996): Effect of indigenous plant materials on the fecundity, adult emergence and development of pulse beetle, *Collosobruchus chinensis* (L.) in blackgrams. *Journal of Research ANGRAU*, **24**: 57–61.
- COBBINAH J.R., APPIAH-KWARTENG J. (1989): Effect of some neem products on stored maize weevil, *Sitophilus zeamais* (MOTSCH). *Insect Science and its Applications*, **10**: 89–92.
- COMPTON J.A.F., FLOYD S., MAGRATH P.A., ADDO S., GBEDEVI S.R., AGBO B., BOKOR G., AMEKUPE S., MOTÉY Z., PENNI H., KUMI S. (1998): Involving grain traders in determining the effect of post-harvest insect damage on the price of maize in African markets. *Crop Protection*, **17**: 483–489.
- DEBBOUN M., FRANCES S.P., STRICKMAN D. (eds) (2007): *Insect Repellents-Principles, Methods and Uses*. CRC Press, Taylor and Francis Group, Boca Raton-London-New York..
- DEMIANYK C.J., SINHA R.N. (1988): Bioenergetics of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) feeding on corn. *Annals of the Entomological Society of America*, **81**: 449–459.
- DETHIER V.G., BROWNE L.B., SMITH C.N. (1960): The design of chemicals in terms of the response they elicit from insects. *Journal of Chemical Entomology*, **53**: 134–136.
- DOBIE P. (1991): *Insects and Arachnids of Tropical Stored Products: their Biology and Identification: A Training Manual*. 2nd Ed. Natural Resources Institute, Chatham.
- GOMEZ K.A., GOMEZ A.A. (1984): *Statistical Procedures for Agricultural Research*. 2nd Ed. Wiley Interscience Publication, New York.
- ISMAN M.B. (2007): Botanical insecticides: for richer, for poorer. *Pest Management Science*, **64** 8–11.
- KÉITA S.M., VINCENT C., SCHMIT J.P., ARNASON J.T., BÉLANGER A. (2001): Efficacy of essential oils of *Ocimum basilicum* L. and *O. gratissimum* L. applied as an insecticidal fumigant and powder to control *Callosobruchus maculatus* (Fab)(Coleoptera: Bruchidae). *Journal of Stored Products Research*, **37**: 339–349.
- KOONA P., TATCHAGO V., MALAA D. (2007): Impregnated bags for safer storage of legume grains in West and Central Africa. *Journal of Stored Products Research*, **43**: 248–251.
- LEE S., PETERSON C.J., COATS J.R. (2003): Fumigation toxicity of monoterpenoids to several stored product insects. *Journal of Stored Products Research*, **39**: 77–85.
- MOORE S.J., LENGLET A.D. (2004): An overview of plants used as insect repellents. In: WILLCOX M., BODEKER G., RASOANAIVO P. (eds): *Traditional Medicinal Plants and Malaria*. Vol. 4. Traditional Herbal Medicine for Modern Times Series. CRC Press, Boca Raton.
- MUGISHA-KAMATENESI M., DENG A.L., OGENDO J.O., OMOLO E.O., MIHALE M.J., OTIM M., BUYUNGO J.P., BETT P.K. (2008): Indigenous knowledge of field insect pests and their management around Lake Victoria basin in Uganda. *African Journal of Environmental Science and Technology*, **2**: 342–348.
- NIBER B.T. (1994): The ability of powders and slurries from 10 plant species to protect stored grain from attack by *Prostephanus truncatus* (HORN) (Coleoptera: Bostrichidae) and *Sitophilus oryzae* (Coleoptera: Curculidae). *Journal of Stored Products Research*, **30**: 297–301.
- OGEMAH V. K. (2003): Influence of neem products on the biology and behaviour of the larger grain borer *P. truncatus*.

- catus* and its predator *Teretrius nigrescens*. [PhD Thesis.] Humboldt University, Germany.
- OGENDO J.O., DENG A.L., BELMAIN R.S., MUSANDU A.A.O. (2004): Effect of insecticidal plant materials *Lantana camara* L. and *Tephrosia vogelli* Hook on the quality parameters of stored maize. The Journal of Food Technology in Africa, **9**: 29–36.
- OGENDO J.O., KOSTYUKOVSKY M., RAVID U., MATASYOH J.C., DENG A.L., OMOLO E.O., KARIUKI S.T., SHAAYA E. (2008): Bioactivity of *Ocimum gratissimum* oil and two constituents against five insect pests attacking stored food products. Journal of Stored Products Research, **44**: 328–334.
- RAHIM M. (1998): Biological activity of azadirachtin-enriched neem kernel extracts against *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) in stored wheat. Journal of Stored Products Research, **34**: 123–128.
- RAJENDRAN S., MURALIDHARAN N. (2005): Effectiveness of allyl acetate as a fumigant against five stored grain beetle pests. Pest Management Science, **61**: 97–101.
- RAJENDRAN S., SRIRANJINI V. (2008): Plant products as fumigants for stored-product insect control (Review). Journal of Stored Products Research, **44**: 126–135.
- REMBOLD H. (1995): Growth and metamorphosis. In: SCHMUTTERER H. (ed.): The Neem Tree: Source of Unique Natural Products for Integrated Pest Management, and Medicinal, Industrial and other Purposes. VCH, Weinheim: 418–432.
- ROSMAN V., KALINOVIC I., KORUNIC Z. (2007): Toxicity of naturally occurring compounds of Lamiaceae and Lauraceae to three stored-product insects. Journal of Stored Products Research, **43**: 349–355.
- SAS (2001): Release 8.02. SAS Institute Inc., Cary.
- SAXENA R.C., DIXIT O.P., HARNASH V. (1992): Insecticidal action of *Lantana camara* against *Callosobruchus chinensis* (Coleoptera: Bruchidae). Journal of Stored Products Research, **28**: 279–281.
- SHARMA R.K. (1995): Neem leaf powder and cop ash against *R. dominica* stored maize. Indian Journal of Entomology, **57**: 15–17.
- SINGH S.C., PANDEY N.K. (1995): Effect of neem on the mortality of the Pulse beetle (*Collosobruchus chinensis* (L.)) on black gram (*Vigna mungo*). Journal of Ecotoxicology and Environmental Monitoring, **5**: 217–218.
- TALUKDER F.A., HOWSE P.E. (1993): Deferent and insecticide effects of extracts of pithraj, *Aphanamixis polystachya* (Meliaceae) against *Tribolium castaneum* in storage. Journal of Chemical Ecology, **19**: 2463–2471.
- TAPONDJOU L.A., ADLER C., BOUDA H., FONTEM D.A. (2002): Efficacy of powder and essential oil from *Chenopodium ambrosioides* leaves as post-harvest grain protectants against six-stored product beetles. Journal of Stored Products Research, **38**: 395–402.
- WANG Z., SONG J., CHEN J., SONG Z., SHANG S., JIANG Z., HAN Z. (2008): QSAR study of mosquito repellents from terpenoid with a six-member-ring. Bioorganic and Medicinal Chemistry Letters, **18**: 2854–2859.
- WAMBUA L.M., DENG A. L., OGENDO J.O., OWUOCHE J., BETT P.K. (2011): Toxic, antifeedant and repellent activity of aqueous crude extracts of *Tephrosia vogelii* Hook on the larval stages of *Helicoverpa armigera* Hubner. Baraton Interdisciplinary Research Journal, **1**: 19–29.

Received for publication November 6, 2011

Accepted after corrections August 8, 2012

Corresponding author.

Dr JOSHUA O. OGENDO, Egerton University, Department of Crops, Horticulture and Soils, P.O. Box 536, Egerton 20115, Kenya; E-mail: ogendojoshua@yahoo.co.uk
