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Research Article

Repellent Effect and Insecticidal Activities of *Bridelia ferruginea*, *Blighia sapida*, and *Khaya senegalensis* Leaves Powders and Extracts against *Dinoderus porcellus* in Infested Dried Yam Chips

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Dinoderus porcellus is considered as the most important pest of stored yam chips and compounds extracted from plants can be used for its control. The present study aimed to test the insecticidal and repellent activities of powders and extracts of leaves of *Bridelia ferruginea*, *Blighia sapida*, and *Khaya senegalensis* against *D. porcellus*. The efficacy of plant powders was compared with the synthetic pesticide Antouka (Permethrin 3 g/kg + pirimiphos 16 g/kg). The results of the experiment revealed that all plant powders were effective as repellents. Antouka was more effective as insecticidal than the plant powders and minimal weight loss was observed with *B. sapida* at 2%. Among treatments, propanol extract of *K. senegalensis* at 5% was found to elicit the highest repellent effect on *D. porcellus*. The LC_{50} results revealed that the acetone extract of *K. senegalensis* is the most toxic (0.29 μL/insect) to the pest, while the propanol extract of *B. ferruginea* at 5% exhibited strong fumigant toxicity against *D. porcellus*, with 88.89% of pest mortality at 160 μL/L air. The findings from the current work proved that plant powders and extracts of the three plants are sources of botanical insecticides which may be used in the integrated management of *D. porcellus*.

1. Introduction

Yam (*Dioscorea* spp.) is an important crop contributing to food security and poverty alleviation in sub-Sahara region, especially in West Africa [1]. In Benin, dehydrated yam chips are the only form in which fresh yam tubers are preserved throughout the year [2]. "Télibo" or "Amala," the traditional thick paste obtained from yam chips flour, is the staple food of many people in Benin [3]. Unfortunately, dried yam chips in traditional storage systems are severely attacked by the beetle *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae) which rapidly reduces yam chips into powder within few days of storage [3, 4]. This pest causes heavy qualitative and quantitative losses during storage [2, 4, 5]. Synthetic insecticides are currently used by farmers to control this pest [2], leading to many cases of food poisoning [6, 7]. The use of these insecticides also leads to a number of problems, such as danger of pesticide misuse, killing of nontarget species, toxicity residues in food, insect resistance, and the destruction of the balance of the ecosystem [8]. Therefore, there is an urgent need to develop an alternative control method that preserves human health and the environment.

Alternatives to these synthetic chemicals are extracts or powders from of some plants [9]. In fact, plants contain bioactive metabolites, which act as antifeedants, repellents, and toxicants against a wide range of insects that attack stored

products [10]. In addition, these indigenous plants, which are used as crude materials to control insect pest infestations, are harvested locally, are cheap, and require only limited processing [11]. In Benin, several medicinal plants such as *Bridelia ferruginea*, *Blighia sapida*, and *Khaya senegalensis* are used by women to control the dried yam beetle *D. porcellus* [2]. In fact, the antifungal [12], antibacterial [13], and insect antifeedant [14] properties of leaf extract of *K. senegalensis* have been demonstrated. The fruit of ackee *(B. sapida)* has insecticide properties [15], whereas the antimicrobial properties of leaves and bark extract of *B. ferruginea* have been proved by Sahu et al. [16]. In order to develop an integrated approach to control and lay the groundwork for the development of a botanical insecticide, experiments should be carried out to assess the insecticidal and repellent effects of these three plants species on *D. porcellus*. In the present study, crude powders and five extracts (acetone, ethanol, methanol, propanol, and distilled water) of *B. ferruginea*, *B. sapida*, and *K. senegalensis* leaves were evaluated for their repellent and insecticidal effects on *D. porcellus*.

2. Material and Methods

2.1. Rearing of Dinoderus porcellus. The beetle *D. porcellus* was reared using healthy yam chips as described by Onzo et al. [17]. Yam chips were sterilized in an oven at 105°C for 2 hours to kill hidden insects and their eggs. The rearing material used is made of plastic containers (19.5 cm height, 6.5 cm diameter). The plastic containers were kept in the laboratory under temperature conditions of 25 ± 2°C, relative humidity of 70 ± 5%, and photoperiodicity of 12L/12D [5]. The containers were placed on shelves in the laboratory. Every two weeks, adult insects were removed in order to synchronize the F1 progeny used for experiments [18].

2.2. Plant Materials. The fresh leaves of *B. ferruginea*, *B. sapida*, and *K. senegalensis* were collected in the town of Parakou (latitude: 9°20′13″N and longitude: 2°37′49″E). Their identity was confirmed by the National Herbarium of the University of Abomey-Calavi. The leaves were washed with tap water to remove debris. The clean leaves were dried during seven days at the room temperature in the shade to prevent the degradation of bioactive compounds by sunlight. The dried leaves were ground into fine powder with an electrical blender and sieved to obtain the finest particles using a 300 μm sieve. The fine powder obtained from each plant species was packed in an airtight container and stored in a cool dry place until use.

2.3. Repellent Activity of Leaf Powder. A bioassay consisting of a circular flat-bottomed plastic basin (26 cm in diameter by 3 cm in height), whose base was divided into five equal portions as described by Ogendo et al. [19], was used to evaluate the repellency of crude *B. ferruginea*, *B. sapida*, and *K. senegalensis* powders against adult *D. porcellus*. Each plant powder was evaluated at four rates (2, 5, 7, and 10% w/w) and commercial synthetic insecticide Antouka (Permethrin 3 g/kg + pirimiphos 16 g/kg; DP) included as a positive control. Treated and untreated yam chips (10 g) were alternately placed equidistantly from the center of the circular base [20]. The treatments were arranged in a completely randomized block design with four replicates per concentration. For each treatment, 20 starved (1 hour of starvation) adults of *D. porcellus* (3–7 days) were released at the center of the basin, which was immediately covered with a transparent muslin, in order to prevent the insects from escaping to the external environment [18]. The total number of insects that settled on the control (P) and the treated yam chips (G) was recorded after 1, 12, and 24 h of exposure. According to Dutra et al. [21], the repellency activity of plant was estimated by calculating the percent repellency (PR) and repellency index (RI). Percent repellency (PR) was calculated using the formula of McDonald et al. [22]:

$$\mathrm{PR} = \left[\frac{(N_c - N_t)}{(N_c + N_t)}\right] \times 100, \tag{1}$$

where N_c is the number of insects on untreated yam chips; N_t is the number of insects on treated yam chips. The mean repellency value of each extract was calculated and assigned to repellency classes from 0 to V: class 0 (PR ≤ 0.1%), class I (PR = 0.1–20%), class II (PR = 20.1–40%), class III (40.1–60%), class IV (60.1–80%), and class V (80.1–100%).

The repellency index (RI) was calculated with the formula:

$$\mathrm{RI} = \frac{2G}{G} + P, \tag{2}$$

where G is the percentage of insects attracted to the treatment and P is the percentage attracted to the control. The RI values range between zero and two [23], and RI = 1 indicates similar repellency between the treatment and the control (neutral treatment), RI > 1 indicates lower repellency of the treatment compared to the control (attractive treatment), and RI < 1 corresponds to a greater repellency of the treatment compared to the control (repellent treatment) [24].

2.4. Contact Toxicity of Plant Powders. The experiment was carried out following the methodology used by Chebet et al. [20]. Leaf powders of the different plants were admixed with 100 g of disinfected yam chips in plastic jars (13 cm in diameter by 10 cm in height) at, respectively, rates (% w/w) of 0, 2, 4, 6, 8, and 10. Yam chips treated with synthetic insecticide Antouka (0.05% w/w) were used as positive control. Ten pairs of adult unsexed insects (3 to 7 days old) were introduced into treated and untreated yam chips. Each jar was covered with a muslin cloth to prevent insects from escaping to the external environment. A completely randomized design with 4 replicates per treatment was used. Data on insect mortality was taken at 1, 3, 5, 7, 14, and 21 days after exposure [25]. The percentage adult mortality was computed according to Asawalam et al. [26] and corrected with Abbott's formula [27] to eliminate natural mortality of control.

$$\text{Percent mortality} = \frac{\text{Number of dead } \textit{D. porcellus}}{\text{Number of introduced } \textit{D. porcellus}} \times 100. \tag{3}$$

$$\text{Corrected mortality} = \frac{(\%\text{ of death in treated} - \%\text{ death in control})}{(100 - \%\text{ death in control})} \times 100. \quad (4)$$

Any living adult insect was removed on day 21 and the percentage weight loss was calculated using the formula

$$\text{Percentage weight loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \quad (5)$$

For determination of F1 progeny emergence, yam chips were checked for adult emergence 35 days after exposure [5] and every 2 days thereafter. In order to avoid a second generation, the sample inspections continued until no more adults emerged during three consecutive inspections [28]. The percent reduction in adult emergence or reproduction inhibition rate (IR%) was computed according to Tapondjou et al. [29] using the formula

$$\text{Reproduction inhibition rate } (\%) = \frac{N_C - N_T}{N_C} \times 100, \quad (6)$$

where N_C is the number of newly emerging adult insects in the untreated control and N_T is the number of newly emerging adult insects in the treated yam chips.

2.5. Preparation of Plant Extracts. The extracts were prepared according to Mansoor-ul-Hasan et al. [30]. Fifty grams of each plant was taken in a beaker separately and mixed with 100 ml of different solvents (acetone, ethanol, methanol, propanol, and distilled water). Then the mixture was stirred for 30 min by a magnetic stirrer (at 6000 rpm) and left to stand for the next 24 hours [31]. The extract was sieved through Whatman filter paper to remove particles. After filtration, the acetone, ethanol, methanol, and propanol extracts were left to evaporate at room temperature during 48 h and the aqueous extract was evaporated under vacuum at 100°C [32]. The extracts were stored at 4°C until further analysis.

2.6. Preparation of Different Concentrations. By diluting the condensed extracts with acetone, ethanol, methanol, propanol, and distilled water, the stock solutions of plant extracts were prepared. Three different concentrations, namely, 2.5, 5.0, and 7.5% of each category of plant extracts were prepared by dissolving the stock solution in the respective solvent [31].

2.7. Repellent Activity Bioassay. The repellency was tested according to Hamouda et al. [32]. Half filter paper discs (Whatman number 40, 9 cm diam.) were prepared and a volume of 200 μl of each plant extract concentration was applied separately to one-half of the filter paper as uniformly as possible with a micropipette. The other half (control) was treated with 200 μl of different solvent (acetone, propanol, ethanol, methanol, and distilled water). Both the treated and the control halves were allowed to dry out as exposed in the air for 10 min. Each treated half disc was then attached lengthwise, edge to edge, to a control half disc with adhesive tape and placed in a Petri dish (9 cm diameter) [32]. Twenty adult insects were released in the middle of each filter paper circle. Each concentration was replicated four times. Insects that settled on each half of the filter paper disc were counted after 15 min, 30 min, and 2 h. The average of the counts was converted to percentage repellency (PR) using the formula of McDonald et al. [22] as in (1).

2.8. Contact Toxicity by Topical Application. Bioassays were conducted according to the method described by Aryani and Auamcharoen [33]. With the help of a pipette, 1 μL solution of each plant extract concentration was applied on the thorax of 10 adults. The control received 1 μL of each solvent (five replications). Each group of ten treated insect individuals was then transferred into a small plastic cup of 8 cm diameter and 5 cm height containing 10 g of yam chips. This experiment was replicated four times and arranged in completely randomized design (CRD). The mortality was recorded after 2, 7, 14, and 21 days [32, 33]. The percentage adult mortality was computed according to Asawalam et al. [26] and corrected for natural mortality using Abbott's formula [27] as in (3) and (4), respectively. Any living adult insect was removed on day 21 and the percentage weight loss was calculated as in (5).

2.9. Fumigation Toxicity Bioassay. Fumigant toxicity of the five solvent extracts of *B. ferruginea*, *B. sapida*, and *K. senegalensis* leaves at the three different concentrations (2.5, 5.0, and 7.5%) was assessed following Nattudurai et al. [34]. An aliquot of 0, 5, 10, 20, and 40 μL of each solvent extract was evenly applied to Whatman number 1 filter paper strips (2 cm diameter) corresponding to the dosages of 0 (as a control), 20, 40, 80, and 160 μL/L air [34]. Each treated paper strip was attached inside the cap of 50 ml glass bottle (4.5 cm in diameter by 13 cm in height) that contained 10 g of yam chips. After release of 10 adult insects the glass bottles were closed airtight by the caps connected to treated paper. After 24 h of treatment, the insects were observed and when there was no leg or antennal movements, insects were considered dead. The experiment was conducted in completely randomized design, with nine treatments and four replicates. Percent insect mortality was calculated and corrected by Abbott's formula [27]. Toxicity ratios (TR) were calculated using the formula used by Gusmão et al. [23]:

$$\text{Toxicity ratios (TR)} = \frac{\text{LC}_{50}\text{ of the extract with less toxicity}}{\text{LC}_{50}\text{ of the other extracts individually}}. \quad (7)$$

2.10. Statistical Analysis. Mortality values were corrected with Abbott's formula to eliminate natural mortality of control. Data on percentage mortality and repellency were arcsine transformed, in order to homogenize their variance before being subjected to one-way ANOVA using IBM SPSS Statistic Software Version 23.0. Significant differences

between means were separated using Least Significant Difference (LSD) at 5% probability. Back-transformed (original) data are given in tables and figures. Data obtained from various concentration-response bioassays (contact toxicity and repellence) were further arcsine transformed before being subject to probit regression analysis using IBM SPSS Statistic Software Version 23.0. Probit analysis was used to calculate the median repellent dose RD_{50} (dose that repelled 50% of the exposed insects). The relationship between the extract concentration applied and percentage mortality was determined using probit regression analysis of transformed data to estimate lethal concentration that kills 50% (LC_{50}) of test insects. Any two LC_{50} values in a column whose 95% confidence limits did not overlap were regarded as significantly different.

3. Results

3.1. Repellent Effect of Plant Powders. Percent repellency of *D. porcellus* adults to yam chips treated with the various crude powder concentrations of *B. ferruginea, B. sapida, and K. senegalensis* is given in Table 1. The magnitude of *D. porcellus* adult repellency was not significantly influenced by plant species ($F = 0.341$, dl = 2, $p \geq 0.05$), concentration of powder applied ($F = 1.477$, dl = 3, $p \geq 0.05$), and exposure time ($F = 1.461$, dl = 2, $p \geq 0.05$). The synthetic insecticide Antouka and all the plant powder possess repellent activity against *D. porcellus* (Table 1). However, repellency of the plant powders was not dose-dependent. The mean percentage repellency value reached 51.3% at the dose of 7% of *K. senegalensis* powder within 24 h of exposure (Table 1). Based on mean repellency rate, powders of all three plants showed repellency classes II and III. The RD_{50} values indicate that synthetic insecticide Antouka repelled *D. porcellus* better than any other plant powders 1 and 12 hours after treatment with a RD_{50} value of 5.4% and 5.9% (w/w), respectively (Table 1), while, 24 hours after treatment, *K. senegalensis* powder was more repellent than the other treatments with a RD_{50} value of 4.1% (w/w).

3.2. Insecticidal Efficiencies of Plant Powders. Contact action of *B. ferruginea*, *B. sapida*, and *K. senegalensis* leaves powders against adult *D. porcellus* is presented in Table 2. The findings of this experiment revealed that insect mortality on yam chips admixed with powders varied with the dosage, the plant tested, and the exposure time (Table 2). The mortality effects of the plant powders on *D. porcellus* were significantly different from the effect of the synthetic insecticide Antouka after 1 day ($F = 2.084$, dl = 15, $p \leq 0.001$), 3 days ($F = 3.831$, dl = 15, $p \leq 0.001$), 5 days ($F = 4.768$, dl = 15, $p \leq 0.001$), and 7 days ($F = 2.260$, dl = 15, $p \leq 0.001$) of exposure. Commercial product Antouka was most effective at all exposure periods and caused 100% mortality of *D. porcellus* 7 days after treatment. However, any significant difference was not observed between synthetic insecticide and plant powders 14 days ($F = 0.797$, dl = 15, $p \geq 0.05$) and 21 days ($F = 0.545$, dl = 15, $p \geq 0.05$) after treatment (Table 2). After 1 day of exposure, a dosage of 2, 4, and 6% (w/w) of *B. sapida* and 8% of *K. senegalensis* powders was not significantly different from that of synthetic insecticide Antouka in terms of *D. porcellus* mortality (Table 2). The same trend was observed with *B. sapida* at 4 and 6%, respectively, 7 and 3 days after treatment (Table 2). Although none of the tested plant powder was able to exert 100% adult mortality, *B. sapida* 4% (w/w) caused 43.7% adult mortality at 21 days after infestation (Table 2). In general, mortality of *D. porcellus* caused by the various concentrations of the three leaf powders tested was higher than those of the control after 14 days of treatment.

The weight loss of yam chips caused by the feeding activity of *D. porcellus* varied in function of plant species and dosage (Table 2). The data recorded at 21 days after treatment registered no weight loss in yam chips treated by the synthetic insecticide Antouka. The highest mean weight loss was 6.7 ± 1.1 g on the untreated control (Table 2). The *K. senegalensis* leaves powder at 8% recorded a significantly ($F = 2.394$, dl = 16, $p \leq 0.001$) higher weight loss when compared to the other treatment (Table 2). Among the plant powder treatments, minimal weight loss was observed in the treatment with *B. sapida* powder at 2% (Table 2).

The adult *D. porcellus* F1 progeny counts in yam chips treated with crude botanical powders were not significantly affected by the plant species ($F = 0.848$, dl = 2, $p \geq 0.05$) and concentration applied ($F = 0.135$, dl = 4, $p \geq 0.05$). Synthetic insecticide Antouka, at 0.05% (w/w), caused the total inhibition (100%) of adult *D. porcellus* F1 progeny emergence. The median developmental time of *D. porcellus* varied significantly ($F = 2.845$, df = 16, $p \leq 0.001$) from 0 days for yam chips treated with synthetic insecticide Antouka to 37.6 days for a dosage of *B. ferruginea* at 10% (Table 3). The reproduction inhibition rate was maximum (100%) in synthetic insecticide Antouka during storage at 21 days after treatment. It was followed by *B. ferruginea* at 4 (50%), 6, and 10% with, respectively, 45% of inhibition rate. In contrast, the *B. sapida* powder at 4 and 10% registered low inhibition rate, that is, 5%, respectively (Table 3).

3.3. Repellency of Plant Extracts. Results given in Table 4 describe the repellent activity of different solvents and concentrations of *B. ferruginea*, *B. sapida*, and *K. senegalensis* leaves crude extracts. The repellency rate of acetone, propanol, ethanol, methanol, and distilled water solvents extract of three plants showed insignificance at different time after treatment (Table 4). The results revealed that repellent activity did not happen significantly at 15 min ($F = 0.822$, df = 44, $p \geq 0.05$), 30 min ($F = 0.926$, df = 44, $p \geq 0.05$), and 2 h ($F = 0.854$, df = 44, $p \geq 0.05$) after treatment. However, even though almost all the plant crude extracts did not show the repellent potential almost at the first 30 min, but as time progressed, the level of repellent activity was increased (Table 4). Among all three plant species and five solvents tested, propanol extract of *K. senegalensis* at 5% was found to elicit significantly ($F = 1.871$, df = 44, $p \leq 0.001$) the highest repellent effect on *D. porcellus* with a percentage repellency of 30% (class II). It was followed by the aqueous extract at 7.5% and propanol extract at 2.5% of *B. sapida* with, respectively, 26.9% (class II) and 22.7% (class II) repellency of *D. porcellus*. Repellency index ranged from 0.7 to 1.2 (Table 4). The acetone extract of *B. ferruginea*, *B.*

Table 1: Percent repellence (mean ± SE) of adult *D. porcellus* and repellent class of *B. ferruginea*, *B. sapida*, and *K. senegalensis* crude powders to varying exposure time and concentrations in a choice bioassay.

Treatments	Concentration (% w/w)	Percent repellency at different time intervals			Mean repellency	Repellency class	Repellency index	Classification
		1 h	12 h	24 h				
Antouka	2.0	35.4 ± 15.8[a]	46.6 ± 9.7[a]	37.7 ± 17.2[a]	39.9 ± 7.7[a]	II	0.60 ± 0.07	Repellent
	5.0	69.0 ± 18.0[a]	37.6 ± 8.8[a]	35.0 ± 13.7[a]	47.2 ± 8.6[a]	III	0.56 ± 0.05	Repellent
	7.0	28.8 ± 41.8[a]	27.8 ± 18.4[a]	52.1 ± 14.9[a]	36.2 ± 14.9[a]	II	0.62 ± 0.06	Repellent
	10.0	75.0 ± 25.0[a]	16.8 ± 18.5[a]	28.8 ± 10.9[a]	40.2 ± 12.5[a]	III	0.61 ± 0.05	Repellent
RD_{50}		5.4	5.9	7.0				
B. ferruginea	2.0	18.9 ± 13.1[a]	42.9 ± 27.4[a]	35.8 ± 18.9[a]	32.5 ± 11.2[a]	II	0.63 ± 0.04	Repellent
	5.0	53.5 ± 18.5[a]	42.1 ± 7.8[a]	43.4 ± 8.4[a]	46.3 ± 6.7[a]	III	0.60 ± 0.04	Repellent
	7.0	51.8 ± 18.3[a]	27.3 ± 9.4[a]	42.0 ± 14.1[a]	40.4 ± 8.1[a]	III	0.61 ± 0.03	Repellent
	10.0	40.0 ± 31.9[a]	15.0 ± 14.0[a]	45.4 ± 8.7[a]	33.5 ± 11.5[a]	II	0.62 ± 0.03	Repellent
RD_{50}		9.6	8.3	7.8				
B. sapida	2.0	27.5 ± 7.5[a]	31.2 ± 18.0[a]	19.8 ± 14.2[a]	26.1 ± 7.4[a]	II	0.63 ± 0.03	Repellent
	5.0	29.9 ± 27.1[a]	47.9 ± 16.8[a]	45.8 ± 11.0[a]	41.2 ± 10.5[a]	III	0.63 ± 0.03	Repellent
	7.0	39.6 ± 15.7[a]	39.1 ± 8.4[a]	41.1 ± 19.3[a]	39.9 ± 7.9[a]	II	0.62 ± 0.02	Repellent
	10.0	53.6 ± 27.0[a]	35.4 ± 20.5[a]	51.3 ± 20.0[a]	46.8 ± 12.1[a]	III	0.61 ± 0.02	Repellent
RD_{50}		9.6	11.6	7.6				
K. senegalensis	2.0	25.0 ± 14.4[a]	25.5 ± 12.3[a]	37.9 ± 11.6[a]	29.4 ± 6.9[a]	II	0.62 ± 0.02	Repellent
	5.0	29.5 ± 30.9[a]	34.5 ± 16.1[a]	42.8 ± 11.7[a]	35.6 ± 11.2[a]	II	0.62 ± 0.02	Repellent
	7.0	25.0 ± 15.0[a]	55.3 ± 18.3[a]	73.7 ± 9.0[a]	51.3 ± 9.7[a]	III	0.60 ± 0.02	Repellent
	10.0	16.9 ± 6.9[a]	47.0 ± 11.3[a]	53.1 ± 6.7[a]	39.0 ± 6.5[a]	II	0.60 ± 0.02	Repellent
RD_{50}		17.9	8.7	4.1				
F		1.507	0.567	0.543	0.896			
p value		0.159	0.880	0.900	0.547			

Means within the same rows followed by the same letter are not significantly different ($p < 0.05$). RD_{50} refers to the concentration (% w/w) that repels 50% of the test insects using probit regression analysis.

Table 2: Mortality of adult *D. porcellus* and weight loss (mean ± SE) of yam chips treated with varying concentration of *B. ferruginea*, *B. sapida*, and *K. senegalensis* crude powders in 21 days after infestation. Mortality rate was corrected using Abbott's formula (4).

Treatments	Concentration (% w/w)	Percentage of mortality rate after different periods of exposures (days)						Weight loss (g)
		1	3	5	7	14	21	
Antouka	0.05	29.4 ± 9.9^{a}	79.1 ± 1.3^{a}	96.8 ± 3.1^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}	0.0 ± 0.0^{c}
B. ferruginea	2.0	1.2 ± 2.4^{d}	0.0 ± 0.0^{c}	0.0 ± 0.0^{d}	0.0 ± 0.0^{c}	5.3 ± 20.1^{a}	8.3 ± 26.4^{a}	3.0 ± 0.4^{abc}
	4.0	0.0 ± 0.0^{d}	0.0 ± 0.0^{c}	0.0 ± 0.0^{d}	1.7 ± 15.8^{c}	12.5 ± 21.5^{a}	8.3 ± 29.5^{a}	2.0 ± 0.7^{abc}
	6.0	1.2 ± 2.4^{d}	0.0 ± 0.0^{c}	0.0 ± 0.0^{d}	0.0 ± 0.0^{c}	10.7 ± 10.3^{a}	18.7 ± 18.1^{a}	2.9 ± 0.7^{abc}
	8.0	2.5 ± 2.0^{bcd}	2.7 ± 4.8^{c}	0.0 ± 5.3^{cd}	3.4 ± 2.8^{b}	32.1 ± 12.2^{a}	41.7 ± 14.8^{a}	2.3 ± 0.6^{abc}
	10.0	1.8 ± 3.8^{d}	0.0 ± 0.0^{c}	0.0 ± 4.4^{d}	1.7 ± 1.7^{b}	17.8 ± 8.5^{a}	29.2 ± 15.4^{a}	2.7 ± 0.6^{abc}
B. sapida	2.0	6.4 ± 2.4^{abcd}	8.3 ± 6.6^{b}	10.9 ± 10.3^{bc}	15.5 ± 17.0^{b}	33.9 ± 19.9^{a}	27.1 ± 24.6^{a}	0.4 ± 0.1^{bc}
	4.0	11.5 ± 3.8^{abc}	11.1 ± 3.9^{bc}	20.3 ± 8.2^{b}	25.9 ± 10.3^{ab}	37.5 ± 17.1^{a}	43.7 ± 21.3^{a}	1.9 ± 0.9^{abc}
	6.0	11.5 ± 2.4^{ab}	19.4 ± 5.3^{ab}	15.6 ± 5.9^{bc}	15.5 ± 7.1^{b}	26.8 ± 6.3^{a}	22.9 ± 10.4^{a}	4.1 ± 1.6^{ab}
	8.0	2.5 ± 2.0^{bcd}	2.7 ± 1.6^{c}	1.5 ± 1.5^{d}	1.7 ± 8.6^{b}	21.4 ± 17.7^{a}	25.0 ± 22.0^{a}	4.1 ± 1.9^{abc}
	10.0	1.2 ± 1.2^{cd}	0.0 ± 2.2^{c}	4.6 ± 4.6^{bcd}	13.7 ± 4.4^{b}	28.5 ± 5.0^{a}	27.0 ± 7.8^{a}	4.1 ± 2.0^{abc}
K. senegalensis	2.0	2.5 ± 2.9^{bcd}	1.3 ± 7.3^{b}	0.0 ± 10.2^{bcd}	0.0 ± 8.8^{b}	10.7 ± 21.1^{a}	0.0 ± 26.6^{a}	3.6 ± 2.0^{abc}
	4.0	1.2 ± 1.2^{cd}	0.0 ± 0.0^{c}	0.0 ± 0.0^{d}	0.0 ± 0.0^{c}	5.3 ± 15.3^{a}	4.1 ± 21.7^{a}	1.5 ± 0.5^{abc}
	6.0	2.5 ± 5.1^{d}	0.0 ± 0.0^{c}	0.0 ± 0.0^{d}	0.0 ± 11.5^{bc}	10.7 ± 19.0^{a}	10.4 ± 24.2^{a}	2.6 ± 1.2^{abc}
	8.0	10.2 ± 7.4^{abcd}	11.1 ± 9.8^{b}	3.1 ± 11.0^{bcd}	0.0 ± 13.2^{bc}	8.9 ± 25.3^{a}	4.1 ± 33.1^{a}	6.4 ± 2.2^{a}
	10.0	0.0 ± 1.3^{d}	0.0 ± 0.0^{c}	0.0 ± 0.0^{d}	6.9 ± 1.9^{bc}	16.0 ± 3.4^{a}	22.9 ± 10.4^{a}	3.9 ± 1.7^{abc}
Control	0	2.5 ± 1.4	10.0 ± 2.8	20.0 ± 6.1	27.5 ± 2.5	30.0 ± 2.0	40.0 ± 3.5	6.7 ± 1.1^{a}

Means in a column followed by different letters are significantly different at $\alpha = 0.05$.

Table 3: Effect of treating yam chips with crude powders of *B. ferruginea*, *B. sapida*, and *K. senegalensis* on F1 progeny emergence and median development time (mean ± SE) of *D. porcellus*.

Treatments	Concentration (% w/w)	Mean number of F1 progenies	Median development time	Reproduction inhibition rate (%)
Control	0.0	5.0 ± 1.9^a	27.7 ± 9.2^b	0.0
Antouka	0.05	0.0 ± 0.0^a	0.0 ± 0.0^a	100.0
B. ferruginea	2.0	3.2 ± 1.6^a	27.6 ± 9.2^b	35.0
	4.0	2.5 ± 1.3^a	27.7 ± 9.7^b	50.0
	6.0	2.7 ± 1.1^a	36.4 ± 0.5^b	45.0
	8.0	3.7 ± 1.2^a	36.4 ± 0.4^b	25.0
	10.0	2.7 ± 0.7^a	37.6 ± 0.4^b	45.0
B. sapida	2.0	3.0 ± 1.2^a	27.7 ± 9.2^b	40.0
	4.0	4.7 ± 2.2^a	36.5 ± 0.5^b	5.0
	6.0	3.7 ± 0.8^a	35.9 ± 0.1^b	25.0
	8.0	3.5 ± 0.8^a	36.2 ± 0.4^b	30.0
	10.0	4.7 ± 1.5^a	36.7 ± 0.6^b	5.0
K. senegalensis	2.0	4.0 ± 1.2^a	36.4 ± 0.5^b	20.0
	4.0	4.2 ± 1.1^a	37.2 ± 0.3^b	15.0
	6.0	4.2 ± 2.1^a	27.1 ± 9.0^b	15.0
	8.0	4.5 ± 1.7^a	37.1 ± 0.6^b	10.0
	10.0	3.7 ± 1.4^a	27.5 ± 9.1^b	25.0

Means in a column followed by different letters are significantly different at $\alpha = 0.05$.

sapida, and *K. senegalensis* at 7.5%, the methanol extract of *B. ferruginea* at 2.5%, and the ethanol extract of *B. sapida* at 7.5% and *K. senegalensis* at 2.5 and 5% were attractant for *D. porcellus* (Table 4). Considering solvents used in this study, repellency of the aqueous extract of *B. sapida* was dose-dependent, comparable to other extracts (Table 4). The comparison among solvents indicates that distilled water and propanol as a solvent were more efficient in extracting bioactive compounds even though the other three solvents also produced some effects (Table 4).

3.4. Contact Toxicity by Topical Application of Plant Extracts. Table 5 summarizes results on the toxicity of the various plant extracts applied topically to *D. porcellus*. The extracts of *B. ferruginea*, *B. sapida,* and *K. senegalensis* caused significant mortality of adult *D. porcellus*. Mortality varied between treatments, concentration, and exposure-period (Table 5). There was a significant ($F = 2.531$, df = 44, $p \leq 0.001$) difference among the extracts 2 days after treatments with acetone extract of *K. senegalensis* at 2.5% inducing the highest mortality of *D. porcellus* and aqueous extract of *B. sapida* at 2.5% the lowest mortality (Table 5). Acetone extract of *B. ferruginea* at 7.5% was significantly most effective at 7 days ($F = 2.984$, df = 44, $p \leq 0.001$) and 14 days ($F = 3.210$, df = 44, $p \leq 0.001$) after treatment while aqueous extract of *B. sapida* at 2.5% was the least. Within 21 days after treatment, aqueous extract of *B. sapida* at 2.5% was significantly ($F = 3.602$, df = 44, $p \leq 0.001$) less toxic to *D. porcellus* compared with the other extracts (Table 5). The LC_{50} ranged from 0.29 μL/insect for acetone extract of *K. senegalensis* to 34.73 μL/insect for methanol extract of *B. ferruginea* (Table 6). According to Table 6, based on the LC_{50}, acetone solvent was more efficient in extracting bioactive compounds of *B. ferruginea* and *K. senegalensis* while for *B. sapida* it was propanol. Table 5 shows that the weight loss caused by the feeding activity of adult *D. porcellus* was significantly ($F = 3.217$, dl = 45, $p \leq 0.001$) lower in the yam chips treated with methanol extract of *B. ferruginea* leaves at 7.5% compared with the other treatments.

3.5. Fumigant Toxicity. Fumigant efficacy tests of the plant extracts showed variable toxicity to adults of *D. porcellus*, depending on plant species and solvents (Figure 1). In all cases, considerable differences in mortality of insects to vapors of extracts were observed with different concentrations (Figure 1). From the graph in Figure 1, it can be seen that propanol extracts of plants were relatively more toxic to *D. porcellus* than the others. The highest concentration (160 μL/L air) of the propanol extract of the three tested plants proved able to induce more than 50% mortality 24 h after treatment (Figure 1). Propanol extract of *B. ferruginea* at 5% exhibits a fumigant toxicity of 88.89% of mortality for a concentration of 160 μL/L air (Figure 1), followed by propanol extract of *B. ferruginea* at 7.5% and propanol extract of *K. senegalensis* at 2.5% causing up to, respectively, 75.56 and 74.48% of pest mortality at the highest concentration. In fumigation tests, LC_{50} ranged from 5.40 to 194.01 μL/L air, while the toxicity ratios ranged from 1.07 to 35.92 (Table 7). Probit analysis showed that *D. porcellus* was more susceptible to propanol extracts of *K. senegalensis* ($LC_{50} = 5.40$ μL/L air) and *B. sapida* ($LC_{50} = 18.68$ μL/L air) which have a toxicity ratio of 35.92 and 10.38, respectively (Table 7).

4. Discussion

Results reported in the current study show that leaves powders of *B. ferruginea*, *B. sapida,* and *K. senegalensis* have repellent effects on *D. porcellus*. The observed repellent activity could partly be attributed to the presence of volatile

Table 4: Repellency rate of different solvent extracts of *B. ferruginea*, *B. sapida*, and *K. senegalensis* on *D. porcellus* leaves at different hours after treatment.

Plants	Solvent used	Concentration of extract (%)	Percent repellency after treatment			Mean repellency	Repellency class	Repellency index	Classification
			15 min	30 min	2 h				
B. ferruginea	Acetone	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	1.8 ± 21.7^{a}	0.0 ± 0.1^{abc}	Class 0	1.0 ± 0.0	Neutral
		5.0	7.1 ± 15.8^{a}	10.0 ± 7.0^{a}	0.0 ± 0.0^{a}	1.5 ± 6.9^{bcd}	Class I	0.9 ± 0.0	Repellent
		7.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.2 ± 13.8^{a}	0.0 ± 0.0^{ab}	Class 0	1.1 ± 0.0	Attractant
	Propanol	2.5	0.0 ± 0.0^{a}	6.6 ± 20.1^{a}	10.6 ± 12.5^{a}	0.0 ± 7.2^{bc}	Class 0	1.0 ± 0.1	Neutral
		5.0	0.0 ± 0.0^{a}	25.0 ± 18.5^{a}	1.2 ± 15.1^{a}	3.4 ± 9.8^{bcd}	Class I	0.9 ± 0.0	Repellent
		7.5	2.1 ± 12.2^{a}	1.0 ± 18.9^{a}	17.5 ± 8.5^{a}	6.9 ± 7.8^{bcd}	Class I	0.9 ± 0.0	Repellent
	Ethanol	2.5	0.0 ± 0.0^{a}	0.5 ± 11.2^{a}	12.5 ± 14.9^{a}	2.8 ± 6.6^{abcd}	Class I	0.9 ± 0.0	Repellent
		5.0	0.0 ± 0.0^{a}	12.5 ± 8.5^{a}	2.5 ± 14.4^{a}	3.2 ± 8.1^{cd}	Class I	0.9 ± 0.0	Repellent
		7.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	19.7 ± 23.0^{a}	3.7 ± 9.9^{cd}	Class I	0.9 ± 0.0	Repellent
	Methanol	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	2.5 ± 11.8^{a}	0.0 ± 0.0^{ab}	Class 0	1.1 ± 0.0	Attractant
		5.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	15.0 ± 8.6^{a}	0.6 ± 7.9^{abc}	Class I	0.9 ± 0.0	Repellent
		7.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	13.4 ± 14.6^{a}	0.0 ± 3.4^{ab}	Class 0	1.0 ± 0.0	Neutral
	Distilled water	2.5	0.0 ± 0.0^{a}	18.1 ± 11.0^{a}	0.0 ± 0.0^{a}	0.0 ± 11.3^{cd}	Class 0	1.0 ± 0.1	Neutral
		5.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	9.3 ± 10.8^{a}	0.0 ± 4.0^{abc}	Class 0	1.0 ± 0.0	Neutral
		7.5	19.2 ± 19.5^{a}	25.0 ± 18.9^{a}	13.0 ± 19.3^{a}	19.0 ± 10.1^{cd}	Class I	0.8 ± 0.1	Repellent
B. sapida	Acetone	2.5	0.0 ± 0.0^{a}	0.0 ± 23.5^{a}	13.6 ± 22.6^{a}	0.3 ± 12.2^{bcd}	Class I	0.9 ± 0.1	Neutral
		5.0	0.0 ± 0.0^{a}	10.0 ± 9.1^{a}	49.7 ± 17.6^{a}	13.8 ± 12.4^{cd}	Class I	0.8 ± 0.1	Repellent
		7.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	Class 0	1.1 ± 0.0	Attractant
	Propanol	2.5	4.6 ± 13.0^{a}	31.1 ± 18.9^{a}	32.5 ± 4.7^{a}	22.7 ± 8.0^{d}	Class II	0.7 ± 0.0	Repellent
		5.0	0.0 ± 0.0^{a}	10.3 ± 16.0^{a}	4.3 ± 16.1^{a}	3.5 ± 9.1^{cd}	Class I	0.9 ± 0.0	Repellent
		7.5	6.3 ± 19.7^{a}	5.7 ± 10.0^{a}	15.8 ± 12.3^{a}	9.3 ± 7.7^{c}	Class I	0.9 ± 0.0	Repellent
	Ethanol	2.5	0.0 ± 0.0^{a}	3.1 ± 20.0^{a}	14.1 ± 6.7^{a}	2.8 ± 7.7^{abcd}	Class I	0.9 ± 0.0	Repellent
		5.0	13.9 ± 18.3^{a}	22.6 ± 18.7^{a}	17.5 ± 19.7^{a}	18.0 ± 9.9^{cd}	Class I	0.8 ± 0.0	Repellent
		7.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	2.5 ± 18.9^{a}	0.0 ± 0.0^{a}	Class 0	1.1 ± 0.1	Attractant
	Methanol	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	11.7 ± 10.4^{a}	0.0 ± 1.3^{abc}	Class 0	1.0 ± 0.0	Neutral
		5.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	Class 0	1.0 ± 0.0	Neutral
		7.5	0.5 ± 10.4^{a}	0.0 ± 0.0^{a}	9.0 ± 7.4^{a}	1.4 ± 4.3^{abc}	Class I	0.9 ± 0.0	Repellent
	Distilled water	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	18.5 ± 4.3^{a}	2.0 ± 5.1^{abcd}	Class I	0.9 ± 0.0	Repellent
		5.0	15.6 ± 15.7^{a}	9.7 ± 25.5^{a}	13.1 ± 12.5^{a}	12.8 ± 9.8^{cd}	Class I	0.8 ± 0.0	Repellent
		7.5	16.8 ± 27.8^{a}	16.9 ± 12.8^{a}	46.9 ± 13.6^{a}	26.9 ± 11.0^{d}	Class II	0.7 ± 0.1	Repellent

Table 4: Continued.

Plants	Solvent used	Concentration of extract (%)	Percent repellency after treatment 15 min	30 min	2 h	Mean repellency	Repellency class	Repellency index	Classification
K. senegalensis	Acetone	2.5	7.5 ± 9.4^{a}	14.4 ± 4.8^{a}	7.5 ± 12.5^{a}	9.8 ± 5.4^{cd}	Class I	0.9 ± 0.0	Repellent
		5.0	0.0 ± 0.0^{a}	2.5 ± 21.4^{a}	0.0 ± 0.0^{a}	0.0 ± 3.1^{abc}	Class 0	1.0 ± 0.0	Neutral
		7.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	1.0 ± 9.7^{a}	0.0 ± 0.0^{a}	Class 0	1.1 ± 0.0	Attractant
	Propanol	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	5.0 ± 11.9^{a}	0.0 ± 1.8^{abc}	Class 0	1.0 ± 0.0	Neutral
		5.0	19.2 ± 10.0^{a}	22.3 ± 16.3^{a}	48.7 ± 10.8^{a}	30.0 ± 7.7^{d}	Class II	0.6 ± 0.0	Repellent
		7.5	2.5 ± 22.9^{a}	0.0 ± 0.0^{a}	17.9 ± 33.7^{a}	5.4 ± 14.3^{cd}	Class I	0.9 ± 0.1	Neutral
	Ethanol	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	Class 0	1.2 ± 0.1	Attractant
		5.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	Class 0	1.2 ± 0.1	Attractant
		7.5	0.0 ± 0.0^{a}	15.0 ± 9.5^{a}	5.9 ± 12.4^{a}	0.4 ± 8.3^{abcd}	Class I	0.9 ± 0.0	Repellent
	Methanol	2.5	3.9 ± 9.3^{a}	8.3 ± 6.8^{a}	6.7 ± 20.5^{a}	6.3 ± 7.1^{cd}	Class I	0.9 ± 0.0	Repellent
		5.0	22.5 ± 7.5^{a}	13.1 ± 12.0^{a}	20.0 ± 14.1^{a}	18.5 ± 6.1^{cd}	Class I	0.8 ± 0.0	Repellent
		7.5	0.0 ± 0.0^{a}	1.3 ± 12.3^{a}	4.4 ± 14.8^{a}	0.0 ± 7.0^{c}	Class 0	1.0 ± 0.0	Neutral
	Distilled water	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	20.0 ± 16.8^{a}	1.4 ± 10.1^{abc}	Class I	0.9 ± 0.1	Neutral
		5.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	Class 0	1.0 ± 0.0	Neutral
		7.5	18.6 ± 9.2^{a}	17.5 ± 25.3^{a}	13.4 ± 20.4^{a}	16.5 ± 10.2^{cd}	Class I	0.8 ± 0.1	Repellent

Means within the same rows followed by the same letter are not significantly different ($p < 0.05$).

Table 5: Mortality rate of *D. porcellus* treated by topical application with acetone, propanol, ethanol, methanol, and aqueous extracts of *B. ferruginea*, *B. sapida*, and *K. senegalensis* and weight loss after 21 days (mean ± SE). Mortality rate was corrected using Abbott's formula (4).

Name of the plant	Solvent used	Concentration of extract (%)	Mortality rate (%) after different periods of exposures (days)				Weight loss (%)
			2	7	14	21	
B. ferruginea	Acetone	2.5	18.9 ± 3.1^{abcd}	51.3 ± 12.8^{de}	56.7 ± 13.2^{cd}	61.9 ± 12.7^{c}	1.2 ± 0.4^{ab}
		5.0	16.2 ± 8.1^{abcd}	40.5 ± 6.9^{cde}	48.6 ± 6.8^{bcd}	50.0 ± 5.6^{bc}	3.2 ± 0.6^{abcd}
		7.5	29.7 ± 3.1^{bcd}	70.2 ± 6.8^{d}	75.6 ± 9.2^{d}	76.4 ± 10.7^{c}	1.2 ± 0.0^{ab}
	Propanol	2.5	-5.4 ± 2.7^{ab}	16.2 ± 5.1^{abcde}	29.7 ± 6.9^{bcd}	38.2 ± 7.4^{bc}	1.3 ± 0.4^{abc}
		5.0	16.2 ± 9.2^{abcd}	32.4 ± 14.2^{bcde}	40.5 ± 10.3^{bcd}	38.2 ± 13.0^{bc}	3.4 ± 0.4^{abcd}
		7.5	27.0 ± 11.1^{abcd}	51.3 ± 6.9^{de}	62.1 ± 3.1^{cd}	61.7 ± 2.9^{c}	1.8 ± 0.5^{abcd}
	Ethanol	2.5	18.9 ± 11.2^{abcd}	40.5 ± 12.8^{cde}	64.8 ± 9.2^{cd}	64.7 ± 8.3^{c}	1.2 ± 0.5^{ab}
		5.0	2.7 ± 4.4^{abcd}	16.2 ± 2.7^{bcde}	29.7 ± 10.3^{bcd}	32.3 ± 15.4^{bc}	3.2 ± 0.6^{abcd}
		7.5	13.5 ± 11.6^{abcd}	27.0 ± 6.8^{bcde}	32.4 ± 5.1^{bcd}	41.1 ± 0.0^{bc}	1.6 ± 0.4^{abcd}
	Methanol	2.5	10.8 ± 8.1^{abcd}	27.0 ± 14.2^{bcde}	35.1 ± 10.8^{bcd}	29.4 ± 11.7^{bc}	2.4 ± 0.9^{abcd}
		5.0	10.8 ± 5.1^{abcd}	37.8 ± 9.2^{cde}	45.3 ± 10.3^{bcd}	35.2 ± 11.2^{bc}	3.0 ± 0.3^{abcd}
		7.5	13.5 ± 7.6^{abcd}	37.8 ± 11.9^{cde}	43.2 ± 9.2^{bcd}	41.1 ± 10.7^{bc}	1.0 ± 0.3^{a}
	Distilled water	2.5	2.7 ± 4.4^{abcd}	2.7 ± 4.4^{abcd}	5.4 ± 5.1^{ab}	8.8 ± 2.9^{bc}	3.1 ± 0.4^{abcd}
		5.0	2.7 ± 4.4^{abcd}	13.5 ± 4.4^{abcde}	18.9 ± 9.3^{bcd}	14.7 ± 8.8^{bc}	4.2 ± 0.7^{d}
		7.5	0.0 ± 2.7^{abcd}	16.2 ± 5.1^{abcde}	18.9 ± 3.1^{bcd}	11.7 ± 3.3^{bc}	3.9 ± 0.1^{bcd}
B. sapida	Acetone	2.5	13.5 ± 7.6^{abcd}	43.2 ± 19.4^{bcde}	51.3 ± 20.9^{bcd}	55.8 ± 18.2^{bc}	1.0 ± 0.3^{ab}
		5.0	13.5 ± 9.8^{abcd}	18.9 ± 11.2^{abcde}	32.4 ± 11.9^{bcd}	29.4 ± 10.7^{bc}	3.6 ± 0.5^{abcd}
		7.5	21.6 ± 2.7^{abcd}	56.7 ± 8.8^{de}	70.2 ± 9.2^{cd}	70.5 ± 7.5^{c}	1.6 ± 0.1^{abcd}
	Propanol	2.5	10.8 ± 6.8^{abcd}	32.4 ± 11.9^{bcde}	40.5 ± 13.6^{bcd}	32.2 ± 14.8^{bc}	1.3 ± 0.3^{abc}
		5.0	18.9 ± 9.3^{abcd}	27.0 ± 10.2^{bcde}	37.8 ± 6.8^{bcd}	35.2 ± 5.8^{bc}	3.8 ± 0.4^{abcd}
		7.5	32.4 ± 5.1^{bcd}	56.7 ± 15.9^{de}	72.9 ± 12.8^{cd}	79.4 ± 10.0^{c}	2.7 ± 0.6^{abcd}
	Ethanol	2.5	5.4 ± 2.7^{abcd}	21.6 ± 5.1^{bcde}	35.1 ± 6.2^{bcd}	48.6 ± 5.1^{bc}	1.1 ± 0.3^{ab}
		5.0	8.1 ± 3.1^{abcd}	27.0 ± 10.2^{bcde}	35.1 ± 12.4^{bcd}	38.2 ± 13.0^{bc}	3.2 ± 0.3^{cd}
		7.5	13.5 ± 4.4^{abcd}	32.4 ± 5.1^{cde}	48.6 ± 5.1^{bcd}	52.9 ± 10.7^{bc}	1.6 ± 0.3^{abcd}
	Methanol	2.5	10.8 ± 9.2^{abcd}	27.0 ± 5.1^{bcde}	43.2 ± 10.2^{bcd}	44.1 ± 14.7^{bc}	2.3 ± 0.7^{abcd}
		5.0	13.5 ± 7.8^{abcd}	35.1 ± 11.6^{cde}	43.2 ± 13.5^{bcd}	41.1 ± 12.7^{bc}	2.6 ± 0.6^{abcd}
		7.5	10.8 ± 11.1^{abcd}	51.3 ± 5.4^{de}	70.2 ± 9.2^{cd}	70.5 ± 7.5^{c}	2.0 ± 0.2^{abcd}
	Distilled water	2.5	-8.1 ± 0.0^{a}	-5.4 ± 2.7^{a}	-2.7 ± 3.1^{a}	-11.7 ± 3.3^{a}	2.2 ± 0.1^{abcd}
		5.0	5.4 ± 8.1^{abcd}	18.9 ± 11.2^{abcde}	27.0 ± 9.2^{bcd}	32.3 ± 10.0^{bc}	2.7 ± 0.4^{abcd}
		7.5	16.2 ± 14.2^{abcd}	29.7 ± 16.2^{abcde}	40.5 ± 18.9^{bcd}	47.0 ± 20.6^{bc}	1.7 ± 0.2^{abcd}

Table 5: Continued.

Name of the plant	Solvent used	Concentration of extract (%)	Mortality rate (%) after different periods of exposures (days)				Weight loss (%)
			2	7	14	21	
K. senegalensis	Acetone	2.5	67.5 ± 10.8^{d}	45.9 ± 7.6^{de}	18.9 ± 5.4^{bcd}	58.8 ± 14.0^{bc}	1.7 ± 0.7^{abcd}
		5.0	37.8 ± 9.2^{bcd}	43.2 ± 8.1^{cde}	51.3 ± 6.9^{cd}	55.8 ± 15.4^{bc}	3.8 ± 0.2^{abcd}
		7.5	18.9 ± 5.4^{abcd}	54.0 ± 8.1^{de}	64.8 ± 6.8^{cd}	70.5 ± 3.3^{c}	2.1 ± 0.7^{abcd}
	Propanol	2.5	54.0 ± 13.5^{cd}	24.3 ± 13.2^{abcde}	29.7 ± 6.9^{bcd}	27.0 ± 9.2^{bc}	1.9 ± 0.3^{abcd}
		5.0	16.2 ± 6.8^{abcd}	37.8 ± 14.2^{cde}	43.2 ± 11.9^{bcd}	38.2 ± 13.0^{bc}	3.9 ± 0.4^{abcd}
		7.5	21.6 ± 8.1^{abcd}	59.4 ± 11.9^{de}	70.2 ± 13.5^{cd}	67.6 ± 14.7^{c}	1.3 ± 0.2^{abc}
	Ethanol	2.5	10.8 ± 2.7^{abcd}	32.4 ± 8.1^{cde}	40.5 ± 6.9^{bcd}	35.2 ± 7.5^{bc}	1.9 ± 0.3^{abcd}
		5.0	18.9 ± 6.9^{abcd}	35.1 ± 7.6^{cde}	40.5 ± 5.4^{bcd}	41.1 ± 4.8^{bc}	4.1 ± 0.4^{abcd}
		7.5	-2.7 ± 7.4^{abc}	21.6 ± 2.7^{bcde}	32.4 ± 2.7^{bcd}	32.3 ± 5.6^{bc}	2.4 ± 0.5^{abcd}
	Methanol	2.5	10.8 ± 6.8^{abcd}	24.3 ± 15.9^{abcde}	32.4 ± 15.5^{bcd}	32.4 ± 18.8^{bc}	1.2 ± 0.4^{ab}
		5.0	16.2 ± 9.2^{abcd}	24.3 ± 11.6^{abcde}	29.7 ± 11.2^{bcd}	26.4 ± 13.0^{bc}	4.4 ± 0.4^{d}
		7.5	21.6 ± 9.2^{abcd}	32.4 ± 5.1^{cde}	51.3 ± 12.8^{bcd}	50.0 ± 16.8^{bc}	1.1 ± 0.4^{ab}
	Distilled water	2.5	-5.4 ± 2.7^{ab}	5.4 ± 13.5^{abc}	13.5 ± 11.6^{abc}	23.5 ± 5.8^{bc}	3.0 ± 1.0^{abcd}
		5.0	-2.7 ± 3.1^{abc}	-2.7 ± 3.1^{ab}	8.1 ± 5.4^{abcd}	5.8 ± 4.8^{b}	4.2 ± 0.3^{d}
		7.5	10.8 ± 5.1^{abcd}	21.6 ± 9.2^{bcde}	40.5 ± 18.4^{bcd}	41.1 ± 22.0^{bc}	2.4 ± 0.8^{abcd}
Control		0	7.5 ± 2.5	7.5 ± 2.5	7.5 ± 2.5	15.0 ± 6.4	4.7 ± 0.3^{d}

Means in a column followed by different letters are significantly different at $\alpha = 0.05$.

Table 6: Contact activity of acetone, propanol, ethanol, methanol, and aqueous extracts of *B. ferruginea*, *B. sapida*, and *K. senegalensis* determined by topical application to *D. porcellus*.

Plants	Solvent used	LC_{50}[a] (μL/insect)	95% confidence interval		Slope ± SE	Intercept ± SE	Chi square (df[b])	p value
			Lower	Upper				
B. ferruginea	Acetone	3.68	1.66	7.57	0.07 ± 0.02	−0.28 ± 0.15	36.32 (10)	0.000
	Propanol	6.77	5.62	9.43	0.14 ± 0.02	−1.01 ± 0.16	29.35 (10)	0.001
	Ethanol	1.53	1.16	4.48	−0.08 ± 0.02	0.13 ± 0.15	41.71 (10)	0.000
	Methanol	34.73	9.03	51.14	0.01 ± 0.02	−0.34 ± 0.15	37.97 (10)	0.000
	Distilled water	24.08	13.06	40.74	0.04 ± 0.03	−1.15 ± 0.18	16.30 (10)	0.091
B. sapida	Acetone	6.92	5.02	12.05	0.06 ± 0.02	−0.43 ± 0.15	89.18 (10)	0.000
	Propanol	5.84	4.59	9.64	0.14 ± 0.02	−0.82 ± 0.15	60.42 (10)	0.000
	Ethanol	11.97	7.96	38.25	0.05 ± 0.02	−0.59 ± 0.15	19.08 (10)	0.039
	Methanol	6.72	5.43	10.16	0.08 ± 0.02	−0.60 ± 0.15	42.48 (10)	0.000
	Distilled water	8.14	6.47	20.16	0.26 ± 0.03	−2.18 ± 0.21	75.11 (10)	0.000
K. senegalensis	Acetone	0.29	0.15	1.14	0.01 ± 0.02	−0.00 ± 0.15	37.37 (10)	0.000
	Propanol	6.04	4.93	8.03	0.10 ± 0.02	−0.61 ± 0.15	53.54 (10)	0.000
	Ethanol	3.84	1.38	6.56	0.04 ± 0.02	−0.17 ± 0.15	16.42 (10)	0.088
	Methanol	10.47	7.67	29.46	0.06 ± 0.02	−0.70 ± 0.15	75.42 (10)	0.000
	Distilled water	11.86	5.26	31.02	0.12 ± 0.03	−1.41 ± 0.18	69.57 (10)	0.000

[a]LC_{50}: lethal concentration 50. [b]df: degrees of freedom.

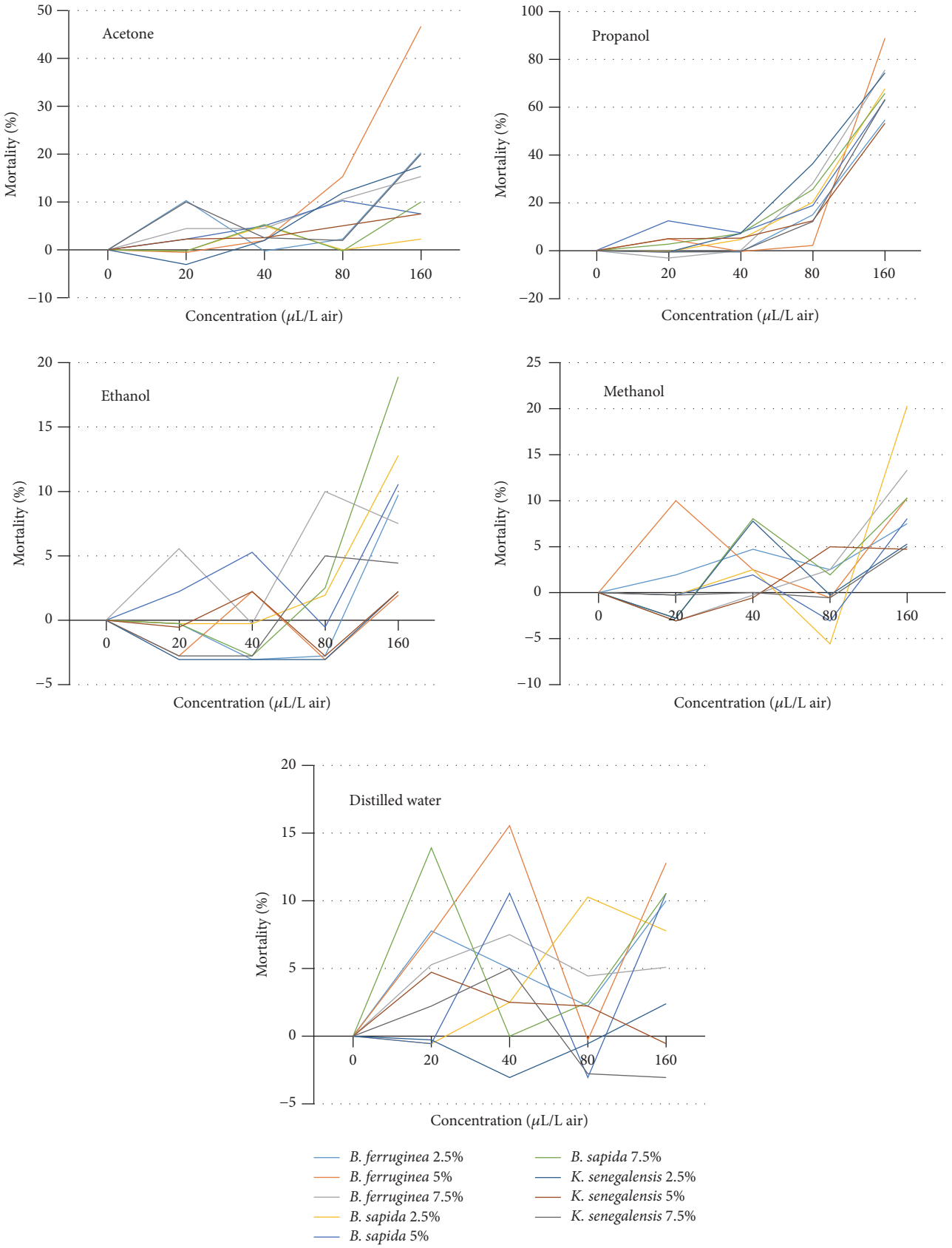

Figure 1: Percentage adult mortality of *D. porcellus* 24 hours after treatment with acetone, propanol, ethanol, methanol, and aqueous extracts of *B. ferruginea*, *B. sapida*, and *K. senegalensis*. Mortality rate was corrected using Abbott's formula (4).

Table 7: Fumigant toxicity of acetone, propanol, ethanol, methanol, and aqueous extracts of *B. ferruginea*, *B. sapida*, and *K. senegalensis* on adult of *D. porcellus* after 24 h exposure.

Plants	Solvent used	LC_{50}[a] (μL/L air)	95% confidence interval		Slope ± SE	Intercept ± SE	Chi square (df[b])	p value	TR_{50}[c]
			Lower	Upper					
B. ferruginea	Acetone	194.01	179.04	205.06	0.00 ± 0.03	−1.02 ± 0.18	100.19 (46)	0.000	—
	Propanol	18.68	10.84	42.65	0.04 ± 0.03	−0.86 ± 0.16	241 (46)	0.000	10.38
	Ethanol	28.45	13.36	91.98	0.06 ± 0.04	−1.77 ± 0.23	74.46 (46)	0.005	6.81
	Methanol	82.28	72.94	108.59	0.01 ± 0.03	−1.24 ± 0.20	43.83 (46)	0.563	2.35
	Distilled water	40.52	33.34	71.68	0.02 ± 0.03	−1.08 ± 0.19	62.51 (46)	0.053	4.78
B. sapida	Acetone	61.75	42.03	80.02	0.02 ± 0.04	−1.46 ± 0.21	50.88 (46)	0.287	3.14
	Propanol	55.90	49.26	68.80	0.01 ± 0.03	−0.61 ± 0.16	168.77 (46)	0.000	3.47
	Ethanol	180.11	165.74	200.55	0.00 ± 0.03	−1.36 ± 0.21	64.26 (46)	0.039	1.07
	Methanol	34.28	21.90	51.62	0.00 ± 0.04	−1.37 ± 0.21	66.53 (46)	0.025	5.65
	Distilled water	96.05	80.28	115.33	0.01 ± 0.03	−1.34 ± 0.20	82.63 (46)	0.001	2.01
K. senegalensis	Acetone	100.38	85.56	119.39	0.01 ± 0.03	−1.24 ± 0.19	70.63 (46)	0.011	1.93
	Propanol	5.40	5.29	6.28	0.06 ± 0.03	−0.32 ± 0.16	190.69 (46)	0.000	35.92
	Ethanol	39.24	22.53	70.12	0.04 ± 0.04	−1.87 ± 0.26	43.36 (46)	0.583	4.93
	Methanol	73.61	64.19	101.25	0.01 ± 0.04	−1.39 ± 0.22	40.41 (46)	0.705	2.63
	Distilled water	150.85	135.78	171.63	0.01 ± 0.04	−1.60 ± 0.24	27.26 (46)	0.987	1.28

[a]LC_{50}: lethal concentration 50. [b]df: degrees of freedom. [c]TR_{50}: toxicity ratio 50.

constituents such as terpenoids in leaves of *B. ferruginea* [35], *B. sapida* [36], and *K. senegalensis* [37], which are well-known repellents of phytophagous insects by acting in the vapor form on the olfactory receptors [38, 39]. The presence of some repellent components such as limonoids, which are highly oxygenated triterpenes, classed as tetranorterpenoides in leaves of *K. senegalensis* [40] could explain their higher repellent activities 24 h after treatment than synthetic insecticide Antouka and other plant powders. The protection of yam chips against insect damage provided by leaf powders of the three plants suggests that there may be an objective basis for their continuous use in traditional yam chips storage systems in Benin [2]. The results indicate that powders of *B. ferruginea*, *B. sapida,* and *K. senegalensis* leaves could be a source of novel repellent against *D. porcellus*. However, there is a need to increase the efficacy of such natural products by developing methods such as mixing with some fixative materials for long lasting efficacy [40].

The result of the study further showed that mortality of *D. porcellus* caused by the various concentrations of the three leaf powders used was higher in comparison with those observed in the negative control. This indicated that the leaf powders were poisonous to adult *D. porcellus* and could serve as a bioinsecticide. The insect mortality may be due to blocking of spiracles of the insect by dust particles and death caused by asphyxia [41]. Plant product may also penetrate the insect body via the respiratory system [42]. Further, Sousa et al. [43] reported that the plant powders caused dehydration to insects by erosion of cuticle layer and their death occurred subsequently. Insecticidal effect of the three botanicals may also be due to its active components. Insecticide activity of *B. sapida* is primarily due to saponins and tannins [36, 44] and might be the cause of the insecticidal activity in this study. *K. senegalensis* leaf powder possesses limonoids which have a wide range of biological activities, including insecticidal, insect antifeedant, and growth regulating activity on insect [14]. Researchers found that *B. ferruginea* has insecticidal properties [45]. However, further investigations are required to determine the efficacy and the active ingredients present in the three plants as well as synthesize them and make scientific formulations for effective use in controlling *D. porcellus*.

Adding powders of *B. ferruginea*, *B. sapida,* and *K. senegalensis* leaves to the yam chips not only increases the mortality of *D. porcellus* but affects the weight loss and the median development time of *D. porcellus* F1 progeny. Similar findings were reported by Mukanga et al. [46] who show that leaf powders of five botanicals (eucalyptus, guava, neem, *Tephrosia*, and water hyacinth) reduce weight loss and clearly suppressed the emergence of *Prostephanus truncatus* populations in dried cassava chips. Based on previous studies, much of the antifeeding of test botanicals could be attributed to their bioactive principles [14, 36, 44, 45]. The inhibition of reproduction rate of *D. porcellus* could be due to the changes in physiology and behaviour in the insect adults due to contact with botanicals that may deter their egg laying capacity [42]. However, the efficacy of the plant products in significantly suppressing emergence has largely been attributed to ovicidal properties, which prevent eggs from hatching into larvae [47] and/or larvicidal activity which caused the larvae from maturing to adult. The good inhibitory effects of powder *B. ferruginea* leaves on the reproductive cycle in which the F_1 progeny was reduced by 50% give a glimmer of hope for use as yam chips protectants against *D. porcellus*.

The results regarding the evaluation of repellent potential of different extracts revealed that the plant crude extracts tested showed a lower repellency than botanical powders. There was considerable variation in the repellent action of the various botanicals extracts. This variation could be explained by the fact that the type of solvent selected affects extract efficacy due to different phytochemicals of varying volatility being present in the final extraction [48]. Among all the plant species, concentrations, and solvents tested, propanol extract of *K. senegalensis* at 5% was found to be the one with the highest repellent effect on *D. porcellus* with percentage repellency of 30%. Strangely, in our laboratory experiments, we found an attractive effect of acetone extract of *B. ferruginea*, *B. sapida,* and *K. senegalensis* at 7.5%, the methanol extract of *B. ferruginea* at 2.5%, and the ethanol extract of *B. sapida* at 7.5% and *K. senegalensis* at 2.5 and 5% on the beetle *D. porcellus* while the other plant extracts were repellent or neutral. The reason for this kind of both repellent and attractant at different concentration is unknown. Similarly, Pugazhvendan et al. [49] found that hexane, chloroform, and ethyl acetate extracts of *Artemisia vulgaris*, *Sphaeranthus indicus*, *Tephrosia purpurea*, and *Prosopis juliflora* can be repellent or attractant on *Tribolium castaneum* at different concentrations. Our findings suggest that there may be different compounds in different solvent extracts possessing different bioactivities. The biological activities of the three tested plants merit further investigation to determine the active ingredients responsible for their repellent or attractant properties.

The results of topical application of crude extracts of *B. ferruginea*, *B. sapida,* and *K. senegalensis* suggest that the leaves of these plants have the greatest potential for insecticidal activity against *D. porcellus*. Earlier studies confirmed the insecticidal effects of these plants species: *B. ferruginea* [45]; *B. sapida* [15, 36, 50–53]; and *K. senegalensis* [54–59]. Acetone extract of *K. senegalensis* showed the lowest LC_{50} and the biggest toxicity ratio, consequently the most toxic on *D. porcellus*. Some studies proved efficacy of *K. senegalensis* for controlling stored products insects such as *Trogoderma granarium* [59], *Callosobruchus maculatus* [54, 55], and *Tribolium confusum* [58]. The phytoconstituents found in the leaf extract of *K. senegalensis* include tannins, saponins, flavonoids, steroids, and alkaloids [37]. The presence of these organic compounds in the plant extract may have been responsible for the mortality of *D. porcellus*. Based on the 24 h LC_{50} values obtained, the acetone extract was more potent than the other extracts used in this study, suggesting that the organic solvent enhanced the extraction/release of the active principle(s). Results indicate that the extracts of the different plants can be incorporated as biopesticides in pest management programs against *D. porcellus*.

Fumigation studies of different plants extracts at different concentrations showed variable toxicity to adults of *D. porcellus*, depending on plant species and solvents. Propanol

extract of *B. ferruginea* at 5% exhibited significant fumigant toxicity to *D. porcellus*. This indicated that propanol extract of *B. ferruginea* at 5% might be useful for managing *D. porcellus* in enclosed spaces such as storage bins, glasshouses, or buildings because of their fumigant action. The fumigant toxicity of propanol extract of *B. ferruginea* at 5% as well as the other plant extracts could be attributed to major constituents such as monoterpenoids [35]; due to their high volatility, they have fumigant and gaseous action which might be of importance for stored-product insects [60]. Monoterpenoids are typically volatile and rather lipophilic compounds, which can rapidly penetrate into insects and interfere with their physiological functions [61]. The results of these fumigation studies indicate that effective extracts of *B. ferruginea*, *B. sapida,* and *K. senegalensis* fumigation treatments against *D. porcellus* can also be potentially applicable in the integrated pest management of this pest.

5. Conclusion

Results from the current study confirmed the importance of the use of *B. ferruginea*, *B. sapida,* and *K. senegalensis* by farmers in Benin to protect stored yam chips of *D. porcellus*. It is evident from the above results that the tested botanical powders are potential protectants (repellents and antifeedants) of stored durable yam chips against *D. porcellus*. The findings of this research have also shown insecticidal effects (contact and fumigation) of extracts of the three medicinal plants. These results indicate that both plant powders and extracts have potential for yam chips protection. They can be used as an alternative to synthetic insecticides. However, the identification and isolation of bioactive compounds from the powders and extracts of these three medicinal plants must be done as key issue for further study.

Conflicts of Interest

The authors have not declared any conflicts of interest.

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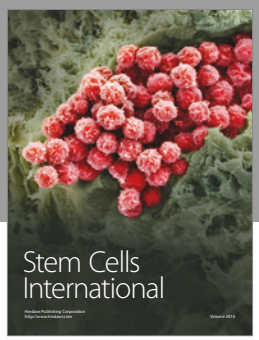

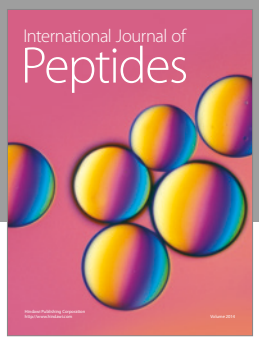

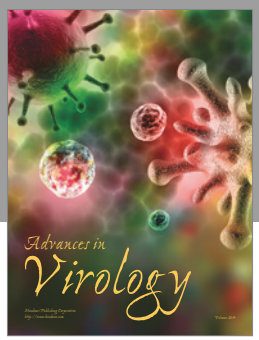

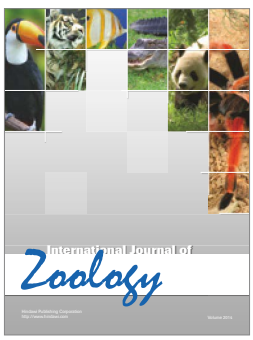

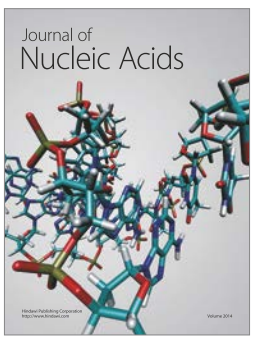

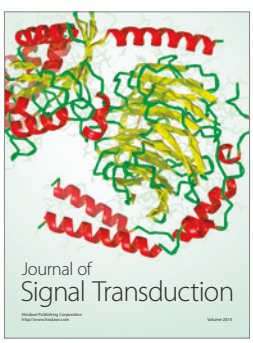

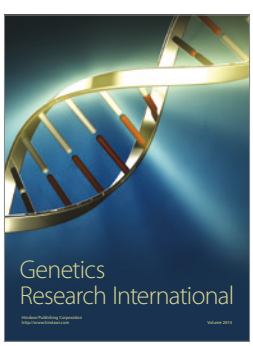

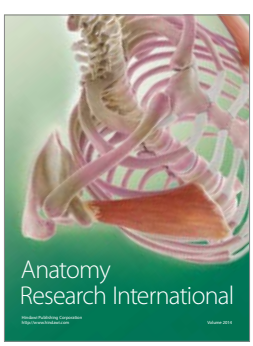

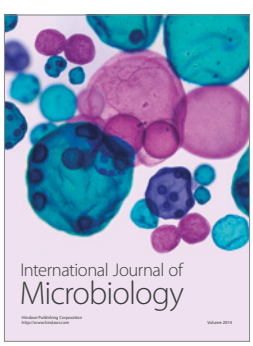

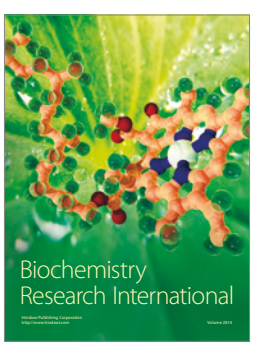

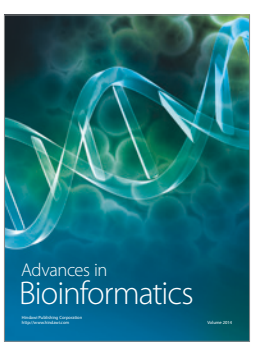

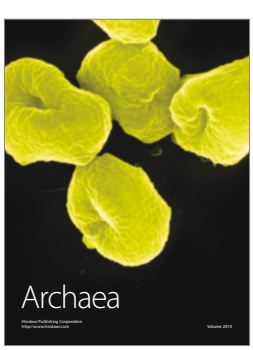

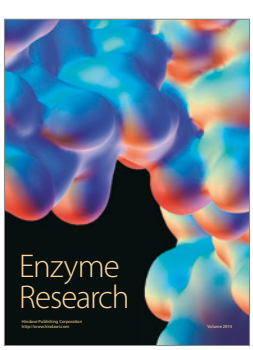

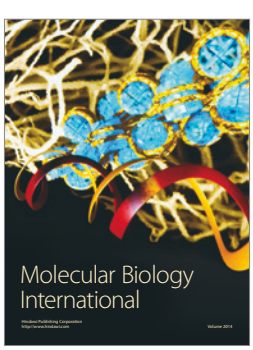

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