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Management of *Dinoderus porcellus* L. (Coleoptera: Bostrichidae) infesting yam chips using varietal resistance and botanical powders of three medicinal plants

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In Benin, stored yam chips are severely attacked by *Dinoderus porcellus* Lesne which causes important losses. The use of medicinal plants combined with the insect-resistant yam chips can be an efficient alternative of chemical insecticides for yam chips protection. This study aims to evaluate an integrated pest management of *D. porcellus* using combined effects of resistant yam chips (Boniwouré, Gaboubaba, Wonmangou, and Yakanougo landraces) and leaves powder of *Bridelia ferruginea* Benth, *Blighia sapida* Juss and *Khaya senegalensis* Cronquist. For that, repellence, weight loss, mortality and progeny production were evaluated with Antouka commercial insecticide as positive control and untreated yam chips as negative control. The results revealed that all treatments are strongly repellent and showed important reproductive inhibition rate and remarkable inhibition of emergency of *D. porcellus* progeny. The weight loss due of yam chips treated with the three medicinal plants was not significantly different from those treated with Antouka, but significantly different from untreated yam chips. Only *K. senegalensis* at 2% (w/w) combined with Wonmangou landrace was able to achieve 66.2% of mortality after 21 days of experimentation. Hence, combination of resistant yam chips with leaves powder of these three medicinal plants could be promoted for integrated management of *D. porcellus*.

Key words: *Dinoderus porcellus*, integrated pest management, medicinal plants, resistance varietal, storage, yam chips.

INTRODUCTION

Yam (*Dioscorea* spp.) is an important crop that contributes to food security and poverty reduction in sub-

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Saharan Africa. Generally, it is cultivated for underground starchy tubers consumption and are mainly produced in West Africa. That production represents 96.3% of the world production (FAO, 2016). Yam tubers are good sources of carbohydrates, dietetary fibers, proteins, vitamin C, and minerals (Opara, 1999; Tortoe et al., 2017) and are eaten on diverse forms: boiled, roasted, fried, pounded, and dough of yam flour (Ayodeji et al., 2012). With an estimated annual production of 3,041,245 tonnes in 2016, Benin ranks fourth behind Nigeria, Ghana and Côte d'Ivoire in yam consumption, with 425 kcal per capital per day (FAO, 2016). Yam production is now entirely part of customs and traditions of populations to the point that we can speak of yam civilization (Baco et al., 2004).

Despite its economic, food and socio-cultural functions, yam production remains hampered by numerous biotic (pests and diseases, etc.) and abiotic (poor soils, climate change, etc.) factors. Also, the difficulty of fresh tubers conservation causes important post-harvest losses (65-85% of the weight of tubers) and an irregularity of its availability throughout the year (Babajide et al., 2008). To overcome the highly perishable nature of tubers, yams are transformed into chips which are traditionally dried under the sun (Hounhouigan et al., 2003), thus enhancing food security (Babajide et al. 2008). Unfortunately, dried yam chips in traditional storage systems are severely attacked by *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae), which easily destroys stocks in few days (Ategbo et al., 1998, Vernier et al., 2005) and can cause losses of up to 50% of stocks (Loko et al., 2013). This pest, also found in dried cassava chips (Schäfer et al., 2000) causes' visual damage by penetrating the chips thus depreciating their market value and negatively influence the quality of reconstituted yam paste (Babarinde et al., 2013). To protect yam chips against insects attack, farmers use chemical insecticides of cotton (Loko et al., 2013), but that leads to several cases of food poisoning and deaths of entire families (Adedoyin et al., 2008; Adeleke, 2009). Due to this deplorable situation, it urges to find out alternative methods that will take into account populations' environment and health protection, and which will be less expensive and available for all. Botanical control meet these criteria and can act as repellents, feeding deterrents, toxicants, growth retardants, and chemosterilants (Hikal et al., 2017). Similarly, genetical control by the use of resistant varieties have enormous potential to reduce storage insect pest populations, and it is an environment-friendly management option (Keneni et al., 2011). Therefore, the use of botanical pesticides and insect-resistant yam chips to control *D. porcellus* appear as a promising alternative.

In the main yam chips production areas of Benin, three medicinal plants (*Bridelia ferruginea* Benth, *Blighia sapida* Juss and *Khaya senegalensis* Cronquist) were recorded as used by farmers to protect their stocks against storage insect pests (Loko et al., 2013). Studies carried out by Loko et al. (2017a) revealed the insect repellency and insecticidal properties of the leaves of these three medicinal plants. Moreover, a study led by Loko et al. (2017b) has allowed to identify four yam landraces (*Gaboubaba*, *Boniwouré*, *Yakanougo* and *Wonmangou*) which chips are resistant to *D. porcellus* attacks. Therefore, to contribute to the strengthening of food security in Benin through the identification of an integrated pest management strategy of *D. porcellus* this study aims evaluate the interactions of resistant yam chips from the four landraces with leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea*.

MATERIALS AND METHODS

Yam landraces source

Tubers of four yam landraces of *Dioscorea cayenensis Lam.* – *Dioscorea rotundata* Poir. complex, belonging to varietal group of "*Kokoro*" were collected from farmers across the Northen and the Central region of the republic of Benin. *Gaboubaba* and *Yakanougo* were collected from Koko village, *Boniwouré* from Kataban village, and *Wonmangou* from Fôbouko village. These 4 landraces were selected according to their resistance to *D. porcellus* (Loko et al., 2017b) and their good agronomic (productivity, number of tubers), culinary (quality of pounded and boiled yam) and technological (quality of yam chips, ease of pounding) characteristics (Loko et al., 2015).

Collection and preparation of medicinal plant powders

Leaves of *B. sapida*, *K. senegalensis* and *B. ferruginea* were collected from the town of Dassa-Zoumé (latitude: 7° 41′ 33″ North, and longitude: 2° 13′ 25″ East). Their identity was confirmed by the National Herbarium of the University of Abomey-Calavi. The collected leaves were washed and dried at ambient temperature for 20 days in the shade in order to prevent the degradation of bioactive compounds by sunlight. After drying, the leaves were transformed into powder using an electrical blender and sieved to obtain the finest particles using a 300 µm sieve (Loko et al., 2017a). The fine powder obtained from each plant species put in black polyethylene bags in dark cool and dry place until use. The compilation of physico-chemical composition of leaves powder of these three medicinal plants on the basis of literature was presented in Table 1.

Processing of yam chips

Yam chips were obtained from processing of tubers of the 4 yam landraces following the method described by Babajide et al. (2006). For that, yam tubers were washed with water to remove sand and other unwanted elements, and peeled with a knife. The tubers were cut into slices of 2 to 3 cm. The yam slices obtained were pre-cooked in water at 50°C for 2 h. They were also macerated in this pre-cooking water for 24 h in order to soften them. The slices were strained and dried in the autoclave at 60°C for at least 3 days in order to have 12 to 14% of final moisture. The dried chips obtained were put in polythene bags and stored in the laboratory at ambient temperature. The chips samples were sterilized at 105°C for 2 h in order to kill the hidden insects and their eggs. The samples were then exposed to ambient temperature for 1 h.

Table 1. Phytochemical composition of the crude water extract of *K. senegalensis*, *B. sapida* and *B. ferruginea* leaves based on literature review.

Phytochemical parameter	Medicinal plants					
	K. senegalensis	**References**	***B. sapida***	**References**	***B. ferruginea***	**References**
Alkaloids	+	Adeiza et al., 2010 Abalaka et al., 2011 Kawo et al., 2011	+	Oreagba et al., 2016	+	Aka and Obidike, 2010 Ameyaw et al., 2012 Abubakar et al., 2017 Houndjo et al., 2017
Tannins	+	Kubmarawa et al., 2008 Adeiza et al., 2010 Abalaka et al., 2011 Kawo et al., 2011	+	Kazeem, et al., 2013 Oreagba et al., 2016	+	Adebayo and Ishola, 2009 Aka and Obidike, 2010 Ameyaw et al., 2012 Abubakar et al., 2017 Houndjo et al., 2017
Saponins	+	Kubmarawa et al., 2008 Adeiza et al., 2010 Abalaka et al., 2011 Kawo et al., 2011	+	Kazeem, et al., 2013 Oreagba et al., 2016	+	Ameyaw et al., 2012 Abubakar et al., 2017
Flavanoids	+	Adeiza et al., 2010	+	Kazeem, et al., 2013 Oreagba et al., 2016	+	Adebayo and Ishola, 2009 Aka and Obidike, 2010 Abubakar et al., 2017 Houndjo et al., 2017
Triterpenoids	+	Adeiza et al., 2010	+	Kazeem, et al., 2013	+	Houndjo et al., 2017
Cardiac glycosides	+	Adeiza et al., 2010	+	Oreagba et al., 2016	+	Adebayo and Ishola, 2009 Aka and Obidike, 2010
Phenols	+	Kubmarawa et al., 2008	+	Oreagba et al., 2016		
Limonoids	+	Olmo et al., 1997	–		–	
Steroids	–		–		+	Ameyaw et al., 2012 Houndjo et al., 2017
Anthraquinones	–		–		+	Ameyaw et al., 2012 Houndjo et al., 2017
Coumarins	–		–		+	Ameyaw et al., 2012 Houndjo et al., 2017

+: Presence, –: Absence.

Rearing of *D. porcellus*

D. porcellus was collected from infested yam chips purchased from Dassa market and maintained on healthy yam chips in the laboratory using the method described by Onzo et al. (2015). The experimental plan was composed of cylindrical plastic boxes opened at one extremity. The opened extremity is covered by a muslin cloth allowing an adequate aeration and preventing insects from running out. Dried yam chips (500 g) were infested in the plastic boxes with 50 adults (3-5 days old) of *D. porcellus*. The plastic boxes were kept on shelves in the laboratory at ambient temperature (Oni and Omoniyi, 2012). After two weeks, adult beetles were removed from the breeding boxes in order to obtain a F1 generation that was used for all experiments (Isha et al., 2009).

Repellence test

The experimental device consisting of a flat circular plastic tray (36 cm in diameter by 2 cm in height) with a cardboard divided into twelve equal compartments and delimited in the centre by a circle having 5 cm of radius glued at the bottom (Babadjide et al., 2008; Loko et al. 2017b), which was used to assess repellency in *D. porcellus* due to yam chips combined with leaves powder of the three medicinal plants. Ten grams of healthy chips of each resistant landrace mixed with a concentration of leaves powder (1, 3, 5, 7 and 10% w/w) were placed in each compartment of tray equidistantly from the centre (Chebet et al., 2013). Similarly, the Antouka commercial insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg; Dustable powder) recommended for the protection of stored food from insect pests was applied on 10 g of untreated yam chips of each landraces at 0.05% (w/w) as recommended by the manufacturer, and put in compartments as positive control (Loko et al. 2017b). While untreated yam chips of the four landraces were used as a negative control. For each treatment, 25 adults of *D. porcellus* (3-7 days old) starved for 24 h were released in the center of the tray, which was immediately covered with a transparent muslin cloth, to prevent the insects from escaping (Isah et al., 2009). The experiments were replicated at 3 different times (15, 30, and 45 days) with 4 replications (a total of 12 repetitions) for each leaves powder concentration. The total number of insects found in untreated yam chips (P) and treated yam chips (G) was recorded after 1, 12, and 24 h of infestation (Loko et al., 2017a). According to Dutra et al. (2016), repellent effect of plants was estimated by calculating the percent repellency (PR) and repellency index (IR). Repulsion percentage (PR) was calculated using the following formula of McDonald et al. (1970):

$$PR = [(Nc - Nt) / (Nc + Nt)] \times 100$$

Where Nc = number of insects present in untreated yam chips; Nt = number of insects present in treated yam chips. The mean repellency value of each treatment was calculated and assigned to the repellent classes from 0 to V: class 0 ($PR \leq 0.1\%$), 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 (IR) was calculated according to the following formula:

$$IR = 2G / G + P$$

Where G = percentage of insects attracted by treated yam chips, and P = percentage of insects attracted by untreated yam chips. The IR values are between 0 and 2 (Gusmão et al., 2013) with, IR = 1 indicates a similar repellency between treated and untreated yam chips (neutral treatment), IR> 1 indicates a lower repellency of treated yam chips compared to untreated yam chips (attractive treatment) and IR <1 correspond to a greater repulsion of treated yam chips compared to untreated yam chips (repellent treatment) (Padín et al., 2013).

Feeding deterrence test

Feeding deterrence test was based on the method used by Isah et al. (2012), and Onzo et al. (2015). For that, 50 g of disinfected yam chips from each resistant landraces mixed with different concentrations of leaves powder of each medicinal plants (1, 3, 5, 7, and 10 % w/w), and Antouka commercial insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg, Dustable powder) at 0.05% (w/w) as a positive control were put in experimental boxes (6 cm in height and 8 cm in diameter). In the experiment, the untreated yam chips were used as negative control. In each box, yam chips of each landrace were infested with 20 adults of *D. porcellus* (3-7 days old) starved for 24 h. These boxes were covered by a muslin cloth to prevent the escape of insects and serves as aeration medium. Each treatment was repeated 4 times. The boxes were placed in the laboratory in a completely randomized block for 30, 60 and 90 days (Isah et al., 2012). At the end of each experimental period, the damage due to *D. porcellus* attacks was evaluated on the basis of proportion of yam chips consumed by the pests. This proportion was estimated according to the formula (Chijindu and Boateng, 2008):

$$\text{Percentage of weight loss} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100$$

Mortality test

Mortality test was conducted according to the methodology used by Chebet et al. (2013) with some modifications. Leaves powder of each of the three medicinal plants were mixed with 100 g of disinfected yam chips of each landrace in plastic boxes (10 cm of high and 13 cm in diameter) at different concentrations (0, 2, 4, 6, 8, 10% w/w). Yam chips impregnated with Antouka synthetic insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg, DP) (0.05% weight/weight) were used as a positive control. Ten pairs of unsexed adult insects were introduced into treated and untreated yam chips. Each box was covered with a transparent muslin cloth, to prevent the insects from escaping. Treatments were arranged in a completely randomised design with 4 replicates. The dead adults were counted after 1, 3, 5, 7, 14 and 21 days of infestation (Othira et al., 2009). The adult mortality rate was calculated according to the formula of Asawalam et al. (2006) and corrected with Abbott's formula (Abbott, 1925) to eliminate the natural mortality of control:

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

$$\text{Corrected mortality } (\%) = \frac{\%\text{ mortality in T} - \%\text{ mortality in C}}{100 - \%\text{ mortality in C}} \times 100$$

Where T = treated yam chips and C = untreated yam chips.

Reproductive inhibition test

Twenty grams of yam chips from the four resistant yam landraces were introduced into the experimental boxes (height: 6 cm and diameter: 8 cm) and mixed with different concentrations of powders of each medicinal plant (1, 3, 5, 7, and 10% w/w) (Chebet et al., 2003), and Antouka commercial insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg; DP) at 0.05% (w/w) as a positive control. The untreated yam chips were used as negative control. Twenty newly emerged adults (3-7 days old) of *D. porcellus* (10 males and 10 females) were introduced into the centre of each experimental box. They were allowed to lay eggs for one week after which they were removed (Chijindu et al., 2008). The treatments were arranged in a completely randomised design with 4 replicates. The emerged adults of F1 progeny were counted 35 days after the begining of experiment. For that, experimental boxes were prospected and emerged adults were collected every 2 days until there is no emerged adult. The percent reduction in adult emergence or reproductive inhibition rate (IR %) was calculated according to Tapondjou et al. (2002) using the formula:

$$\textbf{Reproductive inhibition rate} = \frac{NU - \textbf{NT}}{\textbf{NU}} \times \textbf{100}$$

Where, NU = number of newly emerged adult insects in untreated yam chips, NT = number of newly emerged adult insects in treated yam chips.

Statistical analysis

Data on percentage mortality, repellency, weight loss, and reproductive inhibition were arcsine-transformed (arscine√x), while data on the number of emerged F1 progeny were log-transformed (log(x + 1)) in order to homogenize their variance. The transformed data were then subjected to general linear model (GLM) using IBM SPSS Statistics 25 software package. Significant differences among the means were separated using Student Newman keuls statistic at the 5% level of probability. The original data are presented in tables and figures. Principal component analysis (ACP) was also carried out with Minitab software version 18 in order to examine the contribution of each combination of resistant yam chips treated with leaves powder of medicinal plants on *D. porcellus* control. For that, the different combinations of resistant yam chips and leaves powder of medicinal plants were considered as individuals and corresponding mean values of repellency, mortality, reproductive inhibition, and weight loss were as variables.

RESULTS

Repellent effect of resistant yam chips combined with leaves powder on *D. porcellus*

The synthetic insecticide Antouka and resistant yam chips combined with leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea* at all concentrations had a strong repellent effect on *D. porcellus* (Table 2). However, no significant interaction between resistant yam chips and leaves powder of the three medicinal plants on *D. porcellus* repellency were observed (p ≥ 0.05). Moreover, the interaction between resistant yam chips, medicinal plants and leaves powder concentration on repellence of *D. porcellus* was not significant (p ≥ 0.05) for all treatments. The results showed that percent repellency of *D. porcellus* adults by resistant yam chips treated with different concentration of leaves powder of the three medicinal plants had not varied significantly than commercial insecticide Antouka after 1 h of experiment (p ≥ 0.05). However, yam chips of Yakanougo landrace combined with leaves powder of *B. sapida* respectively at 7 and 3% were more repellent than Antouka insecticide after 12 h (p ≤ 0.05) and 24 h (p ≤ 0.05) of experiment. The results also showed that leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea* had repellent classes ranging from II to IV with a repellency index varying from 0.33 to 0.65 (Table 2). Similarly to Antouka insecticide, leaves powder of *B. sapida* combined with yam chips of Wonmangou landrace at 5 and 7%, Yakanougo landrace at 3, 5 and 7%, and Bonioure landrace at 5 and 7% exhibited a class IV of repellence (Table 1). Similar trend was observed with yam chips of Boniwouré landrace combined with leaves powder of *K. senegalensis* at 5%.

Effect of resistant yam chips combined with leaves powder on *D. porcellus* damages

There was a statistically significant interaction of resistant yam chips combined with leaves powder of the three medicinal plants on reduction of *D. porcellus* damages after 30 (p ≤ 0.05), and 60 (p ≤ 0.05) days of experiments. After 90 days of experimentation this interaction was not significant (p ≥ 0.05). However, no concentration-dependent reduction of weight loss was observed with leaves powder of different medicinal plants (p ≥ 0.05). After 30 days of experiment, only leaves powder of *B. sapida* combined with yam chips of Gaboubaba at 3%, and Wonmangou at 1 and 5% exhibited a significant reduction of weight loss (p ≤ 0.01) than untreated yam chips. The combination of yam chips of resistant landraces with different concentrations of leaves powders of *B. sapida*, *K. senegalensis* and *B. ferruginea* caused a significant reduction of weight loss than untreated yam chips at 60 (p ≤ 0.001), and 90 days (p ≤ 0.001) of experiments. No significant difference was observed between weight loss of yam chips protected with synthethic insecticide Antouka and those protected with leaves powder of the three medicinal plants during all the experimental periods (Table 3).

Effect of resistant yam chips combined with leaves powder on *D. porcellus* mortality

The combination of resistant yam chips with different concentration of leaves powder of the three medicinal plants increased the mortality of *D. porcellus* during all experimental period than untreated yam chips (Figure 1). A significant interaction (p ≤ 0.05) of resistant yam chips treated with different leaves powder concentrations of *K. senegalensis* on *D. porcellus* mortality (Figure 1b) was observed after 1, and 3 days of experiment. However, after 5 days of experiment, no significant interaction (p ≥ 0.05) between resistant yam chips, medicinal plants and leaves powder concentration on *D. porcellus* mortality was recorded. The results showed that mortality was concentration-dependent increasing with increasing dosage of leaves powder of medicinal plants after 21 days of experiment (p ≤ 0.05). The highest mortality was recorded with the synthetic insecticide Antouka with a mean mortality rate of 84.8% (Figure 1). While, the lowest mortality rates were observed on untreated yam chips with a mean mortality rate of 10.5% after 21 days of experiment. The combination of leaves powder of *K. senegalensis* with yam chips of the four resistant landraces at 8%, of leaves powder of *B. sapida* with yam

Table 2. Percent repellence (mean ± SE) of adult *D. porcellus* and repellent class of *B. sapida*, *K. senegalensis*, and *B. ferruginea* leaves powder combined with resistant yam chips at different concentrations and exposure time.

Species name	Landraces	Powders concentration (%)	Percentage of repellency of treatments after			Mean repellency	Repellency class	Repellency index	Classification
			1 h	12	24 h				
B. sapida	Boniwouré	1	57.10 ± 12.0 [a]	49.9 ± 13.10 [a]	51.40 ± 13.5 [ab]	52.83 ± 6.52 [a]	III	0.47 ± 0.06	Repellent
		3	52.10 ± 3.37 [a]	58.00 ± 12.1 [a]	67.41 ± 7.07 [a]	59.20 ± 4.70 [a]	III	0.41 ± 0.05	Repellent
		5	70.79 ± 7.70 [a]	58.1 ± 16.60 [a]	68.33 ± 9.28 [a]	65.73 ± 6.24 [a]	IV	0.34 ± 0.06	Repellent
		7	69.36 ± 4.30 [a]	70.00 ± 5.00 [ab]	62.80 ± 14.8 [ab]	67.38 ± 4.82 [a]	IV	0.33 ± 0.05	Repellent
		10	41.67 ± 8.33 [a]	42.00 ± 8.99 [a]	39.90 ± 12.9 [ab]	41.21 ± 5.15 [a]	III	0.59 ± 0.05	Repellent
	Gaboubaba	1	29.80 ± 10.60 [a]	56.40 ± 15.8 [a]	53.30 ± 15.4 [ab]	46.49 ± 8.21 [a]	III	0.54 ± 0.08	Repellent
		3	47.00 ± 4.56 [a]	56.70 ± 12.0 [a]	56.77 ± 8.43 [ab]	53.48 ± 4.72 [a]	III	0.47 ± 0.05	Repellent
		5	37.00 ± 24.4 [a]	35.00 ± 12.6 [a]	45.66 ± 9.19 [ab]	39.23 ± 8.51[a]	II	0.61 ± 0.08	Repellent
		7	40.70 ± 11.7 [a]	42.42 ± 9.52 [a]	41.40 ± 11.2 [ab]	41.50 ± 5.45 [a]	III	0.59 ± 0.05	Repellent
		10	21.00 ± 12.4 [a]	42.77 ± 1.58 [a]	46.40 ± 17.6 [ab]	36.72 ± 7.39 [a]	II	0.63 ± 0.07	Repellent
	Wanmangou	1	32.06 ± 6.63 [a]	46.67 ± 5.30 [a]	57.20 ± 13.1 [ab]	45.32 ± 5.79 [a]	III	0.55 ± 0.06	Repellent
		3	70.00 ± 5.00 [a]	56.40 ± 3.96 [a]	63.89 ± 7.35 [ab]	58.13 ± 4.95 [a]	III	0.42 ± 0.05	Repellent
		5	63.06 ± 1.94 [a]	66.03 ± 3.31 [a]	61.85 ± 9.21 [ab]	63.65 ± 2.95 [a]	IV	0.36 ± 0.03	Repellent
		7	56.10 ± 12.0 [a]	63.52 ± 5.88 [a]	63.54 ± 4.58 [ab]	61.05 ± 4.26 [a]	IV	0.39 ± 0.04	Repellent
		10	41.67 ± 8. 33 [a]	53.30 ± 14.8 [a]	40.90 ± 17.9 [ab]	45.29 ± 7.41 [a]	III	0.55 ± 0.07	Repellent
	Yakanougo	1	25.93 ± 7.41 [a]	54.60 ± 16.8 [a]	62.10 ± 11.7 [ab]	51.07 ± 7.10 [a]	III	0.49 ± 0.07	Repellent
		3	63.52 ± 5.88 [a]	72.88 ± 4.84 [ab]	73.48 ± 5.30 [a]	69.96 ± 3.13 [a]	IV	0.30 ± 0.03	Repellent
		5	57.8 ± 12.4 [a]	59.30 ± 13.4 [a]	63.80 ± 12.2 [ab]	60.28 ± 6.38 [a]	IV	0.40 ± 0.06	Repellent
		7	74.81 ± 4.12 [a]	75.93 ± 0.93 [b]	68.99 ± 7.16 [a]	73.25 ± 2.63 [a]	IV	0.27 ± 0.03	Repellent
		10	44.80 ± 14.9 [a]	54.40 ± 10.3 [a]	36.30 ± 10.4 [ab]	45.17 ± 6.57 [a]	III	0.55 ± 0.06	Repellent
K. senegalensis	Boniwouré	1	56.61 ± 8.26 [a]	58.10 ± 8.30 [a]	50.80 ± 18.3 [ab]	55.17 ± 6.37 [a]	III	0.45 ± 0.06	Repellent
		3	54.90 ± 11.3 [a]	47.78 ± 7.78 [a]	50.40 ± 12.6 [ab]	52.09 ± 5.14 [a]	III	0.48 ± 0.05	Repellent
		5	57.10 ± 12.0 [a]	64.00 ± 10.7 [ab]	68.33 ± 9.28 [a]	63.17 ± 5.60 [a]	IV	0.37 ± 0.06	Repellent
		7	42.40 ± 16.3 [a]	36.11 ± 7.35 [a]	41.70 ± 10.1 [ab]	40.99 ± 5.79 [a]	III	0.59 ± 0.06	Repellent
		10	51.30 ± 12.4 [a]	37.96 ± 9.12 [a]	41.14 ± 8.86 [ab]	43.45 ± 5.50 [a]	III	0.56 ± 0.05	Repellent
	Gaboubaba	1	59.37 ± 9.78 [a]	36.51 ± 3.17 [a]	25.71 ± 8.73 [b]	40.53 ± 6.31 [a]	III	0.59 ± 0.06	Repellent
		3	39.7 ± 16.8 [a]	41.40 ± 13.9 [a]	27.00 ± 14.3 [b]	36.77 ± 8.17 [a]	II	0.63 ± 0.08	Repellent
		5	25.1 ± 12.5[a]	46.10 ± 2.09 [a]	61.85 ± 9.21 [ab]	44.36 ± 6.98 [a]	III	0.56 ± 0.06	Repellent
		7	46.14 ± 4.78 [a]	36.90 ± 17.5 [a]	26.90 ± 16.1 [b]	37.56 ± 7.41 [a]	II	0.62 ± 0.07	Repellent
		10	44.44 ± 8.01 [a]	63.89 ± 7.35 [ab]	41.96 ± 0.95 [ab]	45.63 ± 7.28 [a]	III	0.50 ± 0.05	Repellent
	Wanmangou	1	63.1 ± 10.2 [a]	36.90 ± 17.5 [a]	58.10 ± 8.30 [ab]	52.70 ± 7.49 [a]	III	0.47 ± 0.07	Repellent
		3	48.6 ± 17.5 [a]	17.86 ± 3.57 [a]	26.43 ± 7.46 [b]	37.70 ± 7.73 [a]	II	0.62 ± 0.08	Repellent
		5	58.10 ± 8.30 [a]	59.30 ± 13.4 [a]	50.84 ± 9.06 [ab]	56.07 ± 5.40 [a]	III	0.44 ± 0.05	Repellent

Table 2. Contd.

		7	46.14 ± 4.78 ^{a}	32.30 ± 19.6 ^{a}	58.30 ± 12.7 ^{ab}	46.11 ± 8.04 ^{a}	III	0.54 ± 0.08	Repellent
		10	49.8 ± 18.3 ^{a}	38.90 ± 14.0 ^{a}	49.10 ± 12.5 ^{ab}	45.91 ± 7.75 ^{a}	III	0.54 ± 0.08	Repellent
		1	45.4 ± 18.6 ^{a}	50.00 ± 9.62 ^{a}	44.40 ± 11.1 ^{ab}	46.60 ± 6.89 ^{a}	III	0.53 ± 0.07	Repellent
		3	42.22 ± 8.89 ^{a}	32.50 ± 10.3 ^{a}	42.40 ± 12.2 ^{ab}	40.25 ± 4.97 ^{a}	III	0.60 ± 0.05	Repellent
	Yakanougo	5	29.8 ± 10.6 ^{a}	45.00 ± 10.4 ^{a}	45.66 ± 9.19 ^{ab}	48.47 ± 8.37 ^{a}	III	0.52 ± 0.08	Repellent
		7	64.3 ± 10.7^{a}	44.40 ± 11.1 ^{a}	55.56 ± 8.01 ^{ab}	55.29 ± 5.94 ^{a}	III	0.45 ± 0.06	Repellent
		10	44. 24 ± 9.47 ^{a}	52. 22 ± 7.78 ^{a}	35.20 ± 10.2 ^{ab}	43.88 ± 5.22 ^{a}	III	0.56 ± 0.05	Repellent
		1	50.8 ± 18.3^{a}	59.50 ± 10.9 ^{a}	53.50 ± 12.1 ^{ab}	54.60 ± 7.19 ^{a}	III	0.45 ± 0.07	Repellent
		3	52.9 ± 13.2^{a}	41.9 ± 11.0 ^{a}	64.00 ± 10.7 ^{a}	52.92 ± 6.68 ^{a}	III	0.47 ± 0.07	Repellent
	Boniwouré	5	47.2 ± 12.1^{a}	27.38 ± 8.33 ^{a}	52.90 ± 19.6 ^{ab}	42.50 ± 8.06 ^{a}	III	0.58 ± 0.08	Repellent
		7	47.1 ± 17.0^{a}	62.70 ± 6.50 ^{ab}	37.96 ± 9.12 ^{ab}	49.25 ± 6.90 ^{a}	III	0.51 ± 0.07	Repellent
		10	52.38 ± 9.52^{a}	48.3 ± 11.7 ^{a}	36.51 ± 3.17 ^{ab}	45.71 ± 5.05 ^{a}	III	0.54 ± 0.05	Repellent
		1	36.51 ± 3.17^{a}	34.49 ± 4.76 ^{a}	42.00 ± 8.99 ^{ab}	37.67 ± 3.27 ^{a}	II	0.62 ± 0.03	Repellent
		3	36.4 ± 19.4^{a}	41.11 ± 4.84 ^{a}	43.30 ± 14.3 ^{ab}	40.26 ± 7.16 ^{a}	III	0.60 ± 0.07	Repellent
	Gaboubaba	5	52.38 ± 9.52^{a}	27.38 ± 8.33 ^{a}	26.74 ± 8.45 ^{b}	35.50 ± 6.09 ^{a}	II	0.65 ± 0.06	Repellent
		7	57.14 ± 9.18^{a}	54.76 ± 8.58 ^{a}	55.95 ± 9.74 ^{ab}	55.95 ± 4.60 ^{a}	III	0.44 ± 0.05	Repellent
		10	39.29 ± 7.43^{a}	44.44 ± 8.01 ^{a}	44.00 ± 13.5 ^{ab}	42.59 ± 5.08 ^{a}	III	0.57 ± 0.05	Repellent
B. ferruginea		1	35.0 ± 12.6^{a}	44.29 ± 2.97 ^{a}	36.40 ± 19.6 ^{ab}	38.56 ± 6.93 ^{a}	II	0.61 ± 0.07	Repellent
		3	40.9 ± 17.9^{a}	42.80 ± 16.6 ^{a}	40.55 ± 3.68 ^{ab}	41.40 ± 7.13 ^{a}	III	0.59 ± 0.07	Repellent
	Wanmangou	5	28.7 ± 11.4^{a}	41.30 ± 15.1 ^{a}	62.22 ± 2.22 ^{ab}	44.07 ± 7.36 ^{a}	III	0.56 ± 0.07	Repellent
		7	36.3 ± 10.4^{a}	46.20 ± 11.3 ^{a}	38.33 ± 7.26 ^{ab}	40.28 ± 5.13 ^{a}	III	0.60 ± 0.05	Repellent
		10	47.62 ± 9.91^{a}	61.67 ± 7.26 ^{a}	56.90 ± 10.7 ^{ab}	55.39 ± 5.13 ^{a}	III	0.45 ± 0.05	Repellent
		1	38.6 ± 17.6^{a}	56.77 ± 8.43 ^{a}	47.62 ± 6.25 ^{ab}	47.67 ± 6.47 ^{a}	III	0.52 ± 0.06	Repellent
		3	53.6 ± 19.7^{a}	46.30 ± 6.68 ^{a}	46.10 ± 2.09 ^{ab}	48.66 ± 6.15 ^{a}	III	0.51 ± 0.06	Repellent
	Yakanougo	5	33.73 ± 5.16^{a}	48.57 ± 5.71 ^{a}	34.40 ± 21.7 ^{ab}	38.90 ± 7.08 ^{a}	II	0.61 ± 0.07	Repellent
		7	41.9 ± 16.5^{a}	54.76 ± 8.58 ^{a}	33.30 ± 12.8 ^{ab}	43.33 ± 7.23 ^{a}	III	0.57 ± 0.07	Repellent
		10	41.7 ± 12.7^{a}	49.63 ± 8.25 ^{a}	45.40 ± 7.80 ^{ab}	45.56 ± 5.06 ^{a}	III	0.54 ± 0.05	Repellent
Control+	Antouka	0.05	56.64 ± 3.15^{a}	60.79 ± 2.41 ^{a}	64.45 ± 2.21 ^{a}	60.85 ± 1.52 ^{a}	IV	0.39 ± 0.01	Repellent

Means within the same rows followed by the same letter are not significantly different using Student Newman Keuls test ($p < 0.05$).

chips of Yakanougo and Bonioué landraces at 6%, and of leaves powder of *B. ferruginea* with yam chips of Gabouba landrace at 6% caused a mortality of more than 50% of the *D. porcellus* population.

Effect of resistant yam chips combined with leaves powder on *D. porcellus* reproduction

A mean number of *D. porcellus* adults emerged from resistant yam chips treated with different concentrations of leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea* was significantly different from those of untreated yam chips after 35 (p ≤ 0.001) and 37 days (p ≤ 0.001) of experimentation (Table 4). However, no significant

Table 3. Weight loss (mean ± SE) of resistant yam chips treated with varying concentrations of leaves powder of *B. sapida*, *K. senegalensis*, and B*. ferruginea* after 30, 60 and 90 days of *D. porcellus* feeding.

Species name	Landraces	Powders concentration (%)	Average weight losses (%) after		
			30 days	60 days	90 days
B. sapida	Boniwouré	1	1.80 ± 0.28 ab	3.40 ± 0.36 b	3.56 ± 0.81 b
		3	1.90 ± 0.57 ab	3.05 ± 0.67 b	4.25 ± 0.51 b
		5	1.66 ± 0.51 ab	3.31 ± 0.36 b	4.31 ± 0.65 ab
		7	1.33 ± 0.39 ab	3.31 ± 0.16 b	4.46 ± 0.25 ab
		10	1.61 ± 0.59 ab	2.91 ± 0.28 b	3.95 ±0.35 b
	Gaboubaba	1	0.45 ± 0.05 ab	2.70 ± 0.42 b	4.10 ± 0.15 ab
		3	0.23 ± 0.06 b	2.30 ± 0.46 b	3.25 ± 0.58 b
		5	0.76 ± 0.36 ab	2.45 ± 0.33 b	3.33 ± 0.47 b
		7	1.15 ± 0.26 ab	2.38 ± 0.23 b	3.31 ± 0.1 b
		10	0.80 ± 0.17 ab	2.23 ± 0.03 b	3.16 ± 0.11 b
	Wanmangou	1	0.33 ± 0.07 b	2.35 ± 0.14 b	3.70 ± 0.18 b
		3	0.88 ± 0.28 ab	2.61 ± 0.43 b	3.70 ± 0.34 b
		5	0.21 ± 0.09 b	2.21 ± 0.16 b	3.85 ± 0.25 b
		7	0.56 ± 0.32 ab	2.23 ± 0.33 b	3.68 ± 0.3 b
		10	0.88 ± 0.15 ab	2.83 ± 0.13 b	4.26 ± 0.18 b
	Yakanougo	1	1.26 ± 0.48 ab	3.41 ± 0.49 b	3.21 ± 1.53 b
		3	1.6 ± 0.44 ab	3.68 ± 0.33 b	5.45 ± 0.52 ab
		5	1.25 ± 0.57 ab	3.01 ± 0.44 b	4.68 ± 0.16 ab
		7	1.11 ± 0.15 ab	3.13 ± 0.12 b	4.30 ± 0.05 ab
		10	1.71 ± 0.14 ab	3.60 ± 0.21 b	3.33 ± 1.17 b
K. senegalensis	Boniwouré	1	1.46 ± 0.22 ab	3.30 ± 0.13 b	4.61 ± 0.27 b
		3	1.68 ± 0.45 ab	3.10 ± 0.52 b	3.96 ± 0.46 b
		5	1.21 ± 0.4 ab	2.86 ± 0.5 b	3.81 ± 0.62 b
		7	1.13 ± 0.28 ab	2.78 ± 0.06 b	3.53 ± 0.04 b
		10	0.71 ± 0.16 ab	2.58 ± 0.18 b	3.48 ± 0.44 b
	Gaboubaba	1	0.68 ± 0.18 ab	1.95 ± 0.24 b	3.35 ± 0.16 b
		3	1.21 ± 0.26 ab	2.20 ± 0.14 b	3.21 ± 0.26 b
		5	1.15 ± 0.28 ab	2.55 ± 0.1 b	3.63 ± 0.19 b
		7	1.15 ± 0.17 ab	2.68 ± 0.36 b	3.43 ± 0.24 b
		10	0.85 ± 0.2 ab	2.58 ± 0.18 b	3.45 ± 0.28 b
	Wanmangou	1	0.75 ± 0.27 ab	2.55 ± 0.32 b	3.78 ± 0.35 b
		3	0.80 ± 0.2 ab	2.78 ± 0.37 b	4.36 ± 0.24 ab
		5	0.55 ± 0.23 ab	2.28 ± 0.06 b	3.61 ± 0.26 b
		7	0.53 ± 0.19 ab	2.13 ± 0.25 b	3.31 ± 0.2 b

Table 3. Contd.

		10	0.71 ± 0.27 ab	2.73 ± 0.46 b	3.60 ± 0.5 b
	Yakanougo	1	0.86 ± 0.21 ab	3.15 ± 0.13 b	4.58 ± 0.23 b
		3	1.28 ± 0.3 ab	2.60 ± 0.25 b	3.48 ± 0.19 b
		5	0.83 ± 0.12 ab	2.66 ± 0.38 b	3.58 ± 0.23 b
		7	1.06 ± 0.09 ab	2.56 ± 0.5 b	3.31 ± 0.39 b
		10	0.93 ± 0.13 ab	2.98 ± 0.33 b	4.06 ± 0.28 ab
B. ferruginea	Boniwouré	1	0.88 ± 0.13 ab	2.73 ± 0.18 b	3.75 ± 0.3 b
		3	1.03 ± 0.27 ab	2.31 ± 0.21 b	2.96 ± 0.21 b
		5	0.76 ± 0.1 ab	3.00 ± 0.72 b	3.81 ± 0.44 b
		7	1.60 ± 0.6 ab	2.95 ± 0.57 b	3.86 ± 0.45 b
		10	1.33 ± 0.23 ab	3.18 ± 0.26 b	4.05 ± 0.24 b
	Gaboubaba	1	1.03 ± 0.13 ab	3.03 ± 0.1 b	3.56 ± 0.4 b
		3	0.78 ± 0.21 ab	2.96 ± 0.2 b	3.73 ± 0.24 b
		5	1.10 ± 0.36 ab	3.36 ± 0.16 b	3.95 ± 0 b
		7	1.15 ± 0.1 ab	2.86 ± 0.31 b	3.93 ± 0.17 b
		10	1.10 ± 0.27 ab	3.30 ± 0.25 b	4.03 ± 0.3 b
	Wanmangou	1	0.51 ± 0.03 ab	2.10 ± 0.17 b	3.40 ± 0.62 b
		3	1.31 ± 0.16 ab	3.63 ± 0.24 b	4.76 ± 0.24 ab
		5	0.70 ± 0.21 ab	2.98 ± 0.19 b	3.71 ± 0.06 b
		7	1.00 ± 0.23 ab	3.15 ± 0.2 b	3.95 ± 0.17 b
		10	1.01 ± 0.22 ab	3.53 ± 0.27 b	4.16 ± 0.22 b
	Yakanougo	1	0.83 ± 0.14 ab	2.80 ± 0.45 b	2.78 ± 0.91 b
		3	0.96 ± 0.26 ab	3.13 ± 0.14 b	3.81 ± 0.24 b
		5	1.66 ± 0.54 ab	2.90 ± 0.53 b	3.86 ± 0.54 b
		7	1.28 ± 0.2 ab	3.33 ± 0.13 b	4.18 ± 0.31 b
		10	1.20 ± 0.4 ab	3.60 ± 0.27 b	4.25 ± 0.24 b
Control +		0.05	1.49 ± 0.08 ab	3.31 ± 0.07 b	4.10 ± 0.10 b
Control -		Any treatment	1.91 ± 0.09 a	4.05 ± 0.17 a	7.54 ± 0.28 a

Means within the same rows followed by the same letter are not significantly different using Student Newman Keuls test ($p < 0.05$).

difference was noted between resistant yam chips treated with leaves powder of the three medicinal plants and insecticide Antouka during experimentations. Significant concentration-dependent reproductive inhibition was observed after 35 days of experimentation (p ≤ 0.05). Signicant interaction between medicinal plants and concentrations of leaves powder on reproductive inhibition rate was observed (p ≤ 0.001) after 35 days of experimentation. The resistant yam chips of the four landraces combined with leaves powder of *K. senegalensis* significantly inhibited *D. porcellus* reproduction (p ≤ 0.001) after 35 days of experimentation. While, in 37 days of experimentation, reproductive

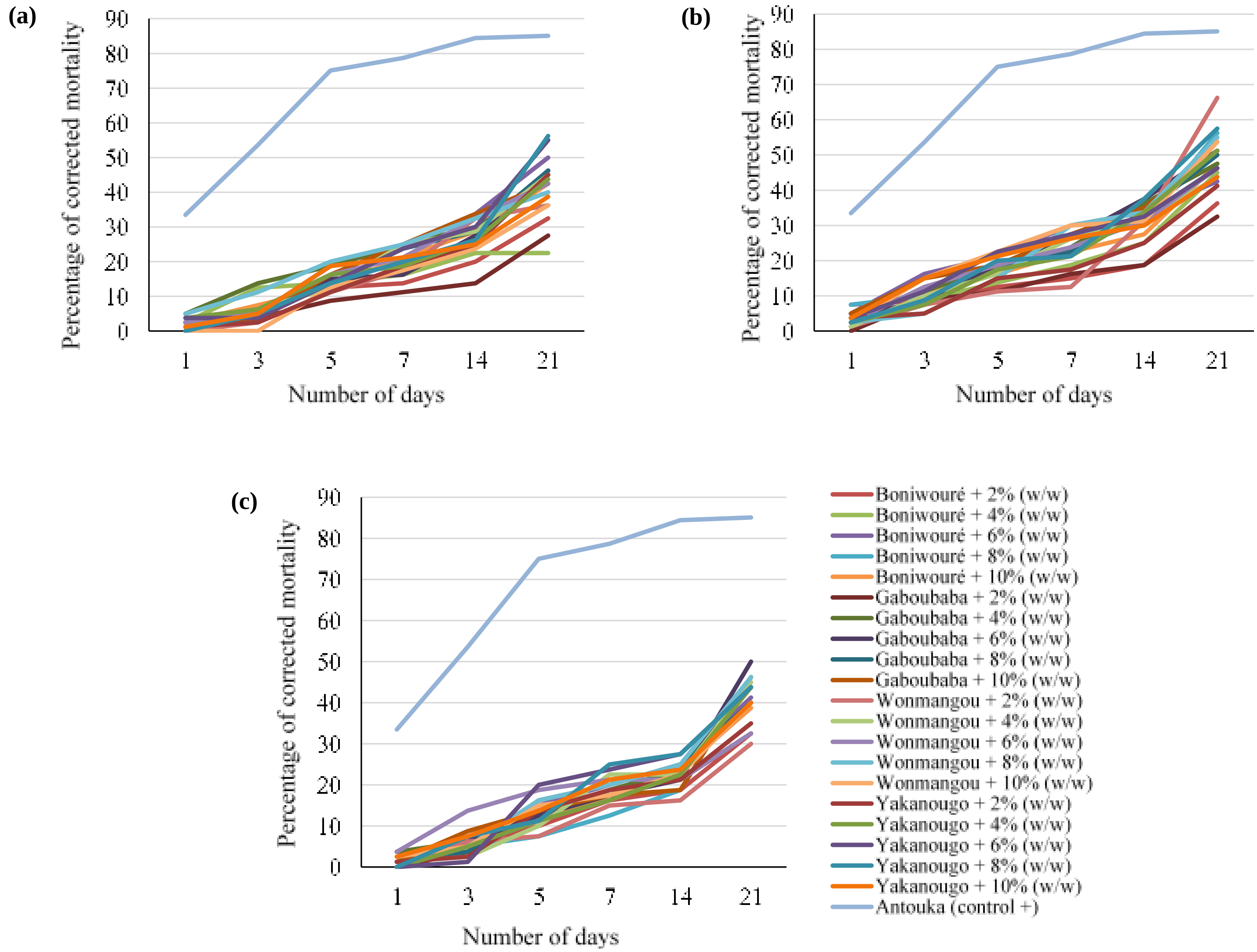

Figure 1. Mortality of *D. porcellus* feeding on resistant yam chips treated with leaves powder of (a) *B. sapida*, (b) *K. senegalensis*, and (c) *B. ferruginea*. Mortality rate was corrected using Abbott's formula.

inhibition rate of all treatments weren't significatively different from what we noticed with synthetic insecticide Antouka, except yakanougo and Bonioué landraces combined respectively with leaves powder of *B. sapida* at 10% and *B. ferruginae* at 5% (Table 4).

Contribution of each combination of resistant yam chips with leaves powder on *D. porcellus* control

Principal component analysis showed that the first three axes represent about 81.5% of total variability. The first axis was positively correlated with weight loss and repellency while the second axis was correlated with mortality and reproductive inhibition of *D. porcellus*. Furthermore, observing the loading plot and the score plot obtained from principal component analysis, the 12 combinations of resistant yam chips treated with leaves powder have been grouped in 4 groups (Figure 2). The first group composed of yam chips of Yakanougo, Wonmangou and Gaboubaba landraces combined with leaves powder of *K. senegalensis* are characterised by their high reproductive inhibition rate of *D. porcellus*. The second group characterised by a strong repellency effect on *D. porcellus* contains yam chips of Bonioué landrace treated with leaves powder of *B. sapida* and *K. senegalensis*, and yam chips of Gaboubaba landrace combined with leaves powder of *B. sapida*. The integration of Gaboubaba with leaves powder of *K. senegalensis* which composed the third group was characterised by a low weight loss. The fourth group was composed of the five remaining combinations which are

Table 4. Effect of yam chips from resistant landraces treated with different concentrations of *B. sapida*, *K. senegalensis* and *B. ferruginea* leaves powder on mean number of emerged adults (mean ± ES) and reproductive inhibition rate of *D. porcellus.*

Treatment	Landraces	Concentration (%w/w)	Mean number of F1 progenies		Reproduction inhibition rate (%)	
			35 days	37 days	35 days	37 days
B. sapida	Boniwouré	1	8.33 ± 2.40 [b]	1.33 ± 0.33 [a]	81.84 ± 3.59 [abc]	90.62 ± 0.87 [ab]
		3	4.00 ± 0.58 [b]	1.67 ± 0.33 [a]	81.95 ± 6.25 [abc]	84.71 ± 4.92 [ab]
		5	6.00 ± 1.53 [b]	1.00 ± 0.58 [a]	81.13 ± 5.90 [abc]	92.49 ± 4.44 [ab]
		7	3.33 ± 0.33 [b]	1.33 ± 0.33 [a]	83.57 ± 2.55 [abc]	84.26 ± 4.63 [ab]
		10	6.33 ± 0.33 [b]	1.33 ± 0.88 [a]	84.21 ± 4.45 [abc]	85.86 ± 9.95 [ab]
	Gaboubaba	1	4.33 ± 1.86 [b]	2.33 ± 0.33 [a]	89.50 ± 5.10 [bcd]	85.47 ± 4.08 [ab]
		3	4.00 ± 0.58 [b]	1.00 ± 0.00 [a]	81.95 ± 6.25 [abc]	90.84 ± 1.91 [ab]
		5	5.67 ± 2.03 [b]	1.67 ± 0.33 [a]	83.95 ± 5.57 [abc]	87.08 ± 1.94 [ab]
		7	3.67 ± 0.88 [b]	1.67 ± 0.33 [a]	83.27 ± 1.27 [abc]	81.02 ± 3.24 [ab]
		10	6.33 ± 1.45 [b]	0.67 ± 0.33 [a]	85.45 ± 3.27 [abc]	93.27 ± 3.42 [ab]
	Wonmangou	1	5.67 ± 0.88 [b]	0.67 ± 0.33 [a]	87.21 ± 1.72 [abc]	95.77 ± 2.41 [ab]
		3	6.00 ± 1.53 [b]	1.33 ± 0.33 [a]	77.88 ± 1.69 [abc]	87.81 ± 3.55 [ab]
		5	5.33 ± 1.45 [b]	2.00 ± 0.58 [a]	82.84 ± 6.61 [abc]	83.87 ± 4.71 [ab]
		7	3.33 ± 1.33 [b]	0.67 ± 0.33 [a]	80.30 ± 11.6 [abc]	92.13 ± 3.96 [ab]
		10	7.67 ± 2.96 [b]	2.00 ± 1.53 [a]	79.14 ± 8.97 [abc]	87.45 ± 8.43 [ab]
	Yakanougo	1	6.00 ± 2.08 [b]	2.33 ± 0.88 [a]	86.23 ± 5.29 [abc]	80.03 ± 8.44 [ab]
		3	7.00 ± 0.58 [b]	1.00 ± 0.58 [a]	69.45 ± 8.90 [abc]	89.77 ± 5.37 [ab]
		5	7.67 ± 1.76 [b]	1.67 ± 0.33 [a]	77.73 ± 3.78 [abc]	87.08 ± 1.94 [ab]
		7	5.00 ± 1.15 [b]	0.33 ± 0.33 [a]	76.54 ± 3.59 [abc]	96.30 ± 3.70 [ab]
		10	6.33 ± 1.76 [b]	2.33 ± 0.88 [a]	85.93 ± 3.68 [abc]	74.36 ± 9.47 [a]
K. senegalensis	Boniwouré	1	7.67 ± 2.19 [b]	1.33 ± 0.33 [a]	81.26 ± 5.84 [abc]	90.61 ± 2.58 [ab]
		3	5.33 ± 1.86 [b]	2.00 ± 0.58 [a]	90.46 ± 1.86 [bcd]	80.03 ± 6.54 [ab]
		5	6.33 ± 1.76 [b]	1.33 ± 0.33 [a]	83.51 ± 3.84 [abc]	90.56 ± 2.16 [ab]
		7	5.33 ± 1.20 [b]	1.67 ± 0.88 [a]	93.34 ± 1.73 [cd]	86.25 ± 7.02 [ab]
		10	5.00 ± 2.08 [b]	2.00 ± 0.58 [a]	89.76 ± 4.47 [bcd]	81.90 ± 4.01 [ab]
	Gaboubaba	1	6.67 ± 0.88 [b]	1.67 ± 0.88 [a]	82.64 ± 5.14 [abc]	87.96 ± 7.23 [ab]
		3	4.00 ± 1.53 [b]	1.67 ± 0.33 [a]	91.07 ± 4.26 [bcd]	84.13 ± 3.54 [ab]
		5	4.00 ± 0.58 [b]	1.67 ± 0.33 [a]	89.33 ± 1.26 [bcd]	87.80 ± 3.33 [ab]
		7	5.33 ± 0.88 [b]	1.67 ± 0.68 [a]	93.54 ± 0.93 [cd]	80.10 ± 11.5 [ab]
		10	5.00 ± 0.58 [b]	1.33 ± 0.33 [a]	89.19 ± 1.37 [bcd]	86.78 ± 4.51 [ab]
	Wonmangou	1	7.67 ± 0.67 [b]	1.33 ± 0.88 [a]	80.06 ± 6.38 [abc]	91.67 ± 4.81 [ab]
		3	5.67 ± 1.76 [b]	1.00 ± 0.58 [a]	89.39 ± 2.89 [bcd]	89.63 ± 5.79 [ab]
		5	3.67 ± 1.20 [b]	1.33 ± 0.33 [a]	90.47 ± 2.61 [bcd]	90.83 ± 1.47 [ab]
		7	3.67 ± 1.20 [b]	1.00 ± 0.00 [a]	95.54 ± 1.37 [cd]	89.64 ± 2.01 [ab]

Table 4. Contd.

		10	5.67 ± 1.33 [b]	1.67 ± 0.68 [a]	86.75 ± 4.25 [abc]	84.43 ± 5.90 [ab]
	Yakanougo	1	5.67 ± 1.20 [b]	1.67 ± 0.33 [a]	84.39 ± 6.72 [abc]	88.36 ± 2.76 [ab]
		3	5.33 ± 1.33 [b]	1.33 ± 0.88 [a]	88.41 ± 5.03 [bcd]	88.60 ± 6.66 [ab]
		5	6.33 ± 0.67 [b]	1.33 ± 0.67 [a]	83.12 ± 0.95 [abc]	91.63 ± 4.21 [ab]
		7	6.33 ± 0.67 [b]	2.00 ± 0.58 [a]	92.14 ± 1.38 [bcd]	79.75 ± 5.80 [ab]
		10	3.33 ± 0.88 [b]	1.33 ± 0.33 [a]	93.05 ± 1.20 [cd]	87.71 ± 2.26 [ab]
B. ferruginea	Boniwouré	1	7.67 ± 2.33 [b]	2.33 ± 0.68 [a]	76.51 ± 6.83 [abc]	80.99 ± 5.60 [ab]
		3	6.00 ± 2.08 [b]	1.33 ± 0.33 [a]	73.63 ± 5.67 [abc]	86.90 ± 2.56 [ab]
		5	5.00 ± 0.58 [b]	2.00 ± 0.58 [a]	91.37 ± 3.07 [abc]	74.89 ± 8.95 [a]
		7	5.00 ± 1.53 [b]	1.00 ± 0.58 [a]	89.97 ± 4.77 [bcd]	86.10 ± 10.0 [ab]
		10	7.00 ± 1.53 [b]	1.67 ± 0.67 [a]	87.33 ± 1.33 [abc]	86.26 ± 6.78 [ab]
	Gaboubaba	1	10.0 ± 1.53 [b]	1.67 ± 0.33 [a]	62.10 ± 15.0 [ab]	86.40 ± 2.86 [ab]
		3	8.67 ± 1.20 [b]	1.00 ± 0.58 [a]	57.40 ± 10.7 [a]	89.63 ± 5.79 [ab]
		5	5.67 ± 2.03 [b]	1.33 ± 0.33 [a]	89.23 ± 5.84 [bcd]	82.68 ± 5.82 [ab]
		7	3.33 ± 0.82 [b]	0.67 ± 0.33 [a]	93.42 ± 2.85 [cd]	92.59 ± 4.90 [ab]
		10	8.00 ± 2.08 [b]	2.33 ± 0.88 [a]	84.43 ± 4.08 [abc]	83.04 ± 5.03 [ab]
	Wonmangou	1	8.00 ± 2.52 [b]	1.00 ± 0.58 [a]	72.50 ± 10.6 [abc]	92.46 ± 4.14 [ab]
		3	5.67 ± 0.33 [b]	2.33 ± 0.68 [a]	69.30 ± 2.00 [abc]	77.21 ± 5.89 [ab]
		5	5.67 ± 2.40 [b]	2.00 ± 1.15 [a]	89.88 ± 4.72 [bcd]	74.90 ± 16.9 [ab]
		7	5.33 ± 0.88 [b]	1.00 ± 0.58 [a]	90.71 ± 1.01 [bcd]	88.89 ± 5.56 [ab]
		10	5.33 ± 0.88 [b]	1.67 ± 0.68 [a]	88.88 ± 3.97 [bcd]	88.16 ± 3.48 [ab]
	Yakanougo	1	7.00 ± 0.58 [b]	1.33 ± 0.88 [a]	75.06 ± 9.07 [abc]	88.64 ± 7.31 [ab]
		3	6.33 ± 1.20 [b]	1.67 ± 0.33 [a]	70.83 ± 3.99 [abc]	83.20 ± 3.60 [ab]
		5	9.00 ± 2.08 [b]	1.00 ± 0.00 [a]	83.58 ± 7.73 [abc]	87.45 ± 1.73 [ab]
		7	6.00 ± 0.58 [b]	1.67 ± 0.33 [a]	88.80 ± 2.96 [bcd]	82.41 ± 7.91 [ab]
		10	6.67 ± 1.20 [b]	1.00 ± 0.58 [a]	87.63 ± 1.10 [abc]	93.27 ± 3.64 [ab]
Control +	Antouka	0.05	0.07 ± 0.04 [a]	0.00 ± 0.00 [a]	99.82 ± 0.12 [d]	100.00 ± 0.00 [b]
Control -	Untreated yam chips	-	45.36 ± 20.27[c]	11.56 ± 3.42[b]	-	-

Means within the same rows followed by the same letter are not significantly different using Student Newman Keuls test ($p < 0.05$).

characterised by a high mortality of *D. porcellus*.

DISCUSSION

The results of this study showed that the combination of yam chips from resistant landraces with leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* has a repellent effect similar to synthetic insecticide Antouka on *D. porcellus.* These results were not surprising because in previous studies leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* (Loko et al., 2017a) as well as yam chips from yam landraces (Loko et al., 2017b) were repellent to *D. porcellus*. Although the interaction between resistant yam chips and medicinal plants has not been significant, the high repellence observed on *D.*

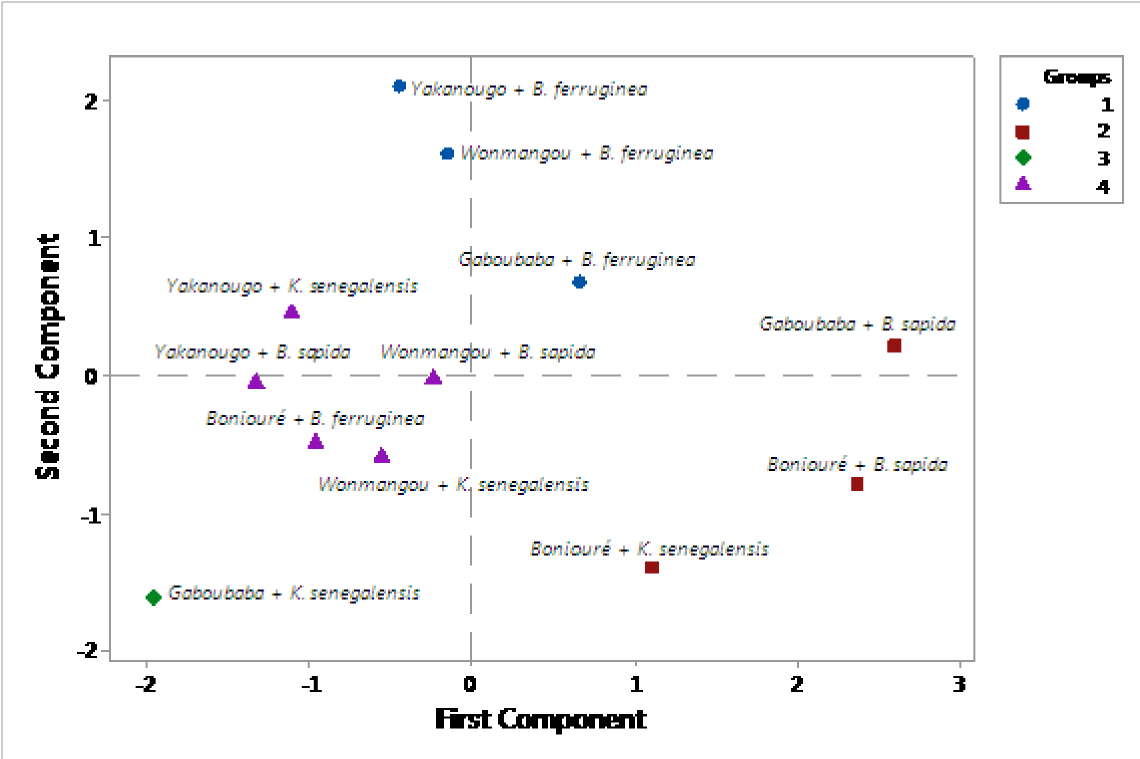

Figure 2. Principal Component Analysis clustering based on repellence, mortality, reproduction inhibition, and weight loss reduction effect of four resistant landraces combined with leaves powder of the three medicinal plants. Group 1: high reproduction inhibition rate of *D. porcellus*; Group 2: strong repellency effect on *D. porcellus*; Group 3: low weight loss; Group 4: high mortality of *D. porcellus*.

porcellus could be due, on one hand to the effect of physicochemical compounds in yam chips and in the other hand to the presence of repulsive volatile substances in the leaves of each of the three medicinal plants (Table 1). Indeed, the color, smell and texture of yam chips could play a determining role in the repulsion of *D. porcellus* (Onzo et al., 2015). In addition, the triterpenoid, tannins and saponoside contained in the leaves powder of *B. ferruginea* (Addae-Mensah and Achenbach, 1985), *B. sapida* (Ubulom et al., 2012) and *K. senegalensis* (Makut et al., 2008) are known repulsive for phytophagous insects because of vapor acting on their olfactory receptors (Moore and Lenglet, 2004). The fact that some associations of resistant landraces and powders of medicinal plants have given a high repulsion values which is above 60% (class IV), revealed the importance of their use in the long-term conservation of yam chips against *D. porcellus;* because stocks can effectively be protected against this pest, thereby tendency for infestation will be reduced.

The weight losses caused by *D. porcellus* on yam chips treated at different concentrations of *B. sapida*, *K. senegalensis* and *B. ferruginea* leaves powder were lower than the one caused on the negative control. According to a previous research, the losses caused by storage insects on the chips depend on some factors such as chips texture (Campbell and Runnion, 2003), partial starch gelatinization after the pre-cooking (which causes the curing of the chips) (Rajamma et al., 1996), biochemical composition of chips (which could encourageor discourage the survival and multiplication of pests) (Wong and Lee, 2011), and environmental conditions (temperature, humidity, etc.) (Chukwulobe and Echezona, 2014). In addition, the combined effect of anti-nutritional factors such as tannins, saponins and phytic acid contained in yam chips (Djeri et al., 2015) and leaves powder of the three medicinal plants tested (*B. sapida*, *K. senegalensis* and *B. ferruginea*) could explain the low weight losses caused by *D. porcellus*. All these factors put together influence the development of *D. porcellus* and therefore reduce the consumption rate of yam chips by this main pest.

The results also showed that the mortality of *D. porcellus* induced by treated yam chips with different concentrations of leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea*. This could be explained by the synergistic effect of antinutritional compounds present in yam chips (Djeri et al., 2015) and the chemical compounds present in leaves powder of medicinal plants (Chebet et al., 2013). Indeed, leaves powder of medicinal plants caused an asphyxiation of insects by penetrating into the internal organs of the insect through its respiratory systems (Fernando and Karunaratne, 2012; Kedia et al., 2015). According to Sousa et al. (2005) vegetables powder involve the dehydration of insects by erosion of cuticle layer which causes the death of the insect. The fact that some combinations of resistant yam chips with leaves powder of medicinal plants at some given concentrations caused mortality rates higher than 50% of *D. porcellus* is promising for the adoption and the use of this integrated method for the management of this pest by farmers. These results are similar to those of Maina and Lale (2004), Babarinde et al. (2008), and Lale and Mustapha (2000), who showed the potential that the integration of insect repellent/insecticidal plant extracts with varietal resistance in the protection of stored products against harmful insects. Thus, the combination of the yam chips of four landraces with leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* must be promoted for the integrated management of *D. porcellus*.

The combination of *B. ferruginea*, *B. sapida* and *K. senegalensis* leaves powder with resistant yam chips caused an inhibition in the reproduction of *D. porcellus* and also affected the mean number of *D. porcellus* adult emerged (F1 progeny). Based on previous studies, the reproductive inhibition of *D. porcellus* may be caused by physiological and behavioral changes in adult insects due to their contact with plant products. This contact could affect their egg-laying ability (Kedia et al., 2015). However, the reduction in the emergence of insects by different plant products is largely related to the ovicidal properties, which prevents the hatching of eggs (Jadhav and Jadhav, 1984) and/or linked to the larvicidal activity, which prevents the larval maturity into adults. Similar studies reported by Mukanga et al. (2010) showed that the powders of five botanical species (eucalyptus, guava, neem, tephrosia and water hyacinth) reduced weight loss and the emergence of *Prostephanus truncatus* populations in dried cassava chips. Nevertheless, exhaustive studies are necessary to identify the active compounds in each of the three medicinal plants and in the yam chips of the four landraces as well as their syntheses for an effective scientific formulation in the control of *D. porcellus*.

Conclusion

Our results showed that the combined use of resistant yam chips and leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* at all concentrations have a great potential for the management of *D. porcellus*. However, further studies will be necessary to identify the active components contained both in the yam chips and in the leaves powder of the three medicinal plants responsible for the repellent and insecticidal effect on *D. porcellus*. Biological activities of leaves powder of these three medicinal plants and resistant landraces associated with their availabilities in Beninese agriculture, make them less expensive than synthetic pesticides for poor-resources farmers. Moreover, combination of resistant yam chips with repellent and insecticidal plants such as *B. ferruginea*, *B. sapida* and *K. senegalensis* for integrated management of *D. porcellus* is an environmental friendly alternative method adapted for small farm holder of the republic of Benin. Because of their strong repellent effect on *D. porcellus*, we recommend for yam chips short term conservation (3-6 months) the use of Bonioure or Gaboubaba landraces treated with leaves powder of *B. sapida*. While for yam chips long term conservation we recommend the use of Yakanougo, Wonmangou or Gaboubaba landraces combined with leaves powder of *K. senegalensis* because of their high reproductive inhibition rate of *D. porcellus*.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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