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ENTOMOLOGY | RESEARCH ARTICLE

Resistance of dried chips of yam (*Dioscorea cayenensis*-*D. rotundata* complex) landraces to *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae)

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Abstract: Yams (*Dioscorea* spp.) are one of the food crops that contribute to food security and poverty alleviation in Benin and, like several other products, the post-harvest phase is threatened by the rotting of fresh tubers. To overcome this constraint, yam tubers are traditionally processed into dried chips which unfortunately are severely attacked by *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae). Research studies on relative resistance of dried chips of 24 yam landraces to the attack of *D. porcellus* during storage were carried out using free-choice tests (antixenosis) and non-choice tests under laboratory conditions. Attractiveness of yam chips, mortality of initial pest populations, weight loss, and also the Dobie's index of susceptibility were considered as indicators of resistance. The results revealed that the landraces Boniwouré and Wonmangou were significantly less attractive and consumed by *D. porcellus*. The highest mortality rate of *D. porcellus* was observed on the landrace Boniwouré followed by Alahina. Based on the Dobie index of susceptibility five yam landraces (Gaboubaba, Boniwouré, Alahina, Yakanougo, and Wonmangou) were scored as resistant to *D. porcellus*. All the remaining landraces were categorized as moderately resistant. Based on the present study, these five resistant landraces deserve special consideration and may be recommended for relatively longer storage to achieve the goal of sustainable management of *D. porcellus*.

ABOUT THE AUTHORS

Laura Estelle Yéyinou Loko is a lecturer-researcher at the Faculty of Sciences and Technology of Dassa of the National University of Sciences, Technology, Engineering and Mathematics of Abomey (Benin republic). Her research interests lie in entomology, plant genetic resources and crop protection. Her current research interests include the development and implementation of Pest Management practices for stored food product.

PUBLIC INTEREST STATEMENT

Yam is an important tuber crop that highly contributes to food security and poverty alleviation in Benin. However, yam tubers are highly perishable with 30 to 85 % post-harvest losses. In Benin, dehydrated yam chips are the only form in which fresh yam tubers are preserved throughout the year. Unfortunately, dried yam chips in traditional storage systems are severely attacked by insects which rapidly reduces yam chips into powder within few days of storage. Synthetic insecticides are currently used by farmers to control these pests, leading to many cases of food poisoning. This study proposed the use of resistant varieties as an economically feasible, technically easy and environmentally friendly alternative to minimize losses to storage insect pests. Five resistant landraces to yam chips insect storage pests were identified and can be included in the production system of yam in Benin meant for chips production.

Subjects: Pest Management; Entomology

Keywords: antixenosis; antibiosis; *Dinoderus porcellus*; varietal resistance; yam chips

1. Background

Yams (*Dioscorea* spp.) serve as an important source of carbohydrates for many people of the sub-Saharan region, especially in the yam zone of West Africa (Sartie, Franco, & Asiedu, 2012). In Benin, the fourth largest yam producer next to Nigeria, Ivory Coast and Ghana, yam is among the most important food crops with an annual production of 3.22 million tonnes (FAO, 2014). It is generally grown for its tubers, which represent the staple food of more than half of the population of Benin (Djoï & Monhouanou, 2003). In Benin, yam production is fully part of the customs and traditions of the people, to a point where we can speak of yam civilization (Baco, Tostain, Mongbo, Dainou, & Agbangla, 2004). More than a subsistence crop, yam has become a commercial crop and plays a key role at both the economical as well as the socio-cultural levels (Baco, Tostain, Mongbo, Biaou, & Lescure, 2007).

However, yam remains a seasonal crop and the fresh tubers are very perishable with an estimated post-harvest losses ranging from 30 to 85% of the total production (Babajide, Atanda, Ibrahim, Majolagbe, & Akinbayode, 2008). To minimize the post-harvest loss and its seasonal supply, yams are traditionally processed into chips (Akissoé et al., 2001; Hounhouigan, Kayodé, Bricas, & Nago, 2003). Unfortunately, yam chips are often severely attacked by storage insect pests, which can devastate the entire stocks into powder within a few months after storage (Ategbo et al., 1998; Babarinde, Babarinde, Odewole, & Alagbe, 2013; Oni & Omoniyi, 2012; Vernier, Goergen, Dossou, Letourmy, & Chaume, 2005). Previous studies undertaken in Benin (Loko et al., 2013) and in Nigeria (Oni & Omoniyi, 2012) revealed that the beetle *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae) is the most important pest of yam chips. In order to protect stored yam chips against this pest, some producers used chemical insecticides recommended for insect pests of cotton (Loko et al., 2013) which caused many cases of food poisoning on humans (Adedoyin, Ojuawo, Adesiyun, Mark, & Anigilage, 2008; Adeleke, 2009). It is therefore utmost important to find alternative management methods to protect the yam chips, and consequently to preserve both human health and the environment.

Thus, the search for easily available, eco-friendly, and cost effective insect pest management options are of paramount importance. One of the alternative management options is the use of resistant yam landraces against insect pests of yam including *D. porcellus*. The use of resistant varieties is economically feasible, technically easy and environmentally friendly alternative to minimize losses to storage insect pests (Dansì et al., 2013). Previous studies also indicated that farmers have a strong preference for yam varieties whose chips are resistant to storage insect pests (Loko et al., 2013). Owing to the large diversity of yam germplasms in Benin, a participatory evaluation of yam landraces was conducted in 51 major yam production villages of the country and assessed 64 landraces whose chips were identified as being resistant to storage insect pests (Loko, Adjatin, Dansì, Vodouhè, & Sanni, 2015). This study evaluates chips of yam landraces of Benin for their resistance to *D. porcellus* based on a susceptibility index.

2. Materials and methods

2.1. Yam landraces

The plant material consisted of 24 yam landraces (*D. cayenensis*-*D. rotundata* complex) belonging to the “Kokoro” variety group. The choice of these 24 yam landraces within the pool of the 64 landraces previously identified (Loko et al., 2015), was made on a basis of their agronomic (productivity, number of tubers), culinary (quality of pounded and boiled yam) and technological (quality of yam chips, ease of pounding) characteristics. The tubers of these 24 landraces were collected from farmers across northern and central Benin (Table 1) and processed into yam chips.

Table 1. List of yam landraces and geographical location of villages where they were collected

No	Landrace name	Villages	Districts
1	Ayé	Fôbouko	Sinendé
2	Baniouré souan	Koko	Tchaourou
3	Boniwouré	Kataban	Copargo
4	Gaboubaba	Koko	Tchaourou
5	Gonopkèssa	Sonnoumon	N'dali
6	Alahina	Awaya	Dassa
7	Kaagourou	Niaro	Sinendé
8	Kouanan	Sonnoumon	N'dali
9	Singor	Fôbouko	Sinendé
10	Singou	Fôbouko	Sinendé
11	Wonmangou	Fôbouko	Sinendé
12	Yakanougo	Koko	Tchaourou
13	Déba	Koko	Tchaourou
14	Kinkérékou	Fôbouko	Sinendé
15	Kokoro agbalè	Banon	Banté
16	Kokoro lakolako	Banon	Banté
17	Koriodjo	Banon	Banté
18	Koumanan	Koko	Tchaourou
19	Kourokourogouroko	Koko	Tchaourou
20	Omonya	Koko	Tchaourou
21	Otoukpanan	Koko	Tchaourou
22	Agada bangahi	Banon	Banté
23	Souwoukou	Koko	Tchaourou
24	Yasssou bagarou	Fôbouko	Sinendé

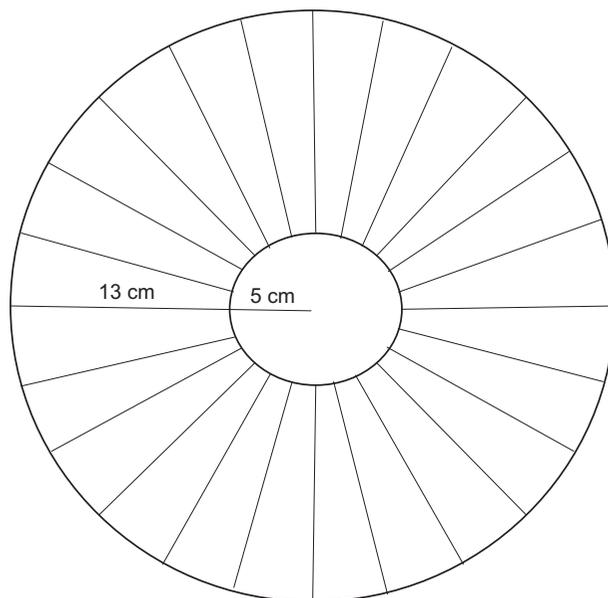
2.2. Processing of yam chips

Yam chips were obtained using the method described by Babajide, Oyewole, Henshaw, Babajide, and Olasantan (2006). To remove soil and other unwanted material yam tubers were washed with water and peeled with knife, and subsequently cut into slices of 2 to 3 cm of thickness. The yam slices were pre-cooked in water at 50°C for 2 h and allowed to macerate in the cooking water for 24 h to soften them. The slices were drained and dried in an oven at 60°C for 5 days to give a final moisture content of about 12 to 14%. The obtained dry chips were stored in polyethylene bags at room temperature in the laboratory. Prior to their use, chips were sterilized in an oven at 105°C for 2 h to kill hidden insects and their eggs, and left to cool down at room temperature for 1 h (Oni & Omoniyi, 2012).

2.3. Rearing of *Dinoderus porcellus*

Rearing of *D. porcellus* was done on healthy yam chips as described by Onzo, Biau, Loko, Tamo, and Dansi (2015). Insect rearing was done in plastic containers (19.5 cm height, 6.5 cm diameter) kept in a wire-netted and gauzed shelf to prevent attack from other pests and promote a stable condition for reproduction (Babarinde, Sosina, & Oyeyiola, 2008). Insect colonies were raised by infesting 500 g of sterilized yam chips in plastic containers with 200 mixed sex adults of *D. porcellus* obtained from the infested yam chips from Dantokpa market located in Cotonou. Each plastic container was covered with a transparent muslin cloth held in place by a rubber band, in order to prevent the insects from escaping. The plastic containers were kept in the laboratory at 25 ± 2°C, 70 ± 5% R.H. and 12L:12D photoperiod (Oni & Omoniyi, 2012). Every two weeks, adult *D. porcellus* were removed in order to synchronize the F1 progeny that was used for the experiments (Isah, Ayertey, & Boateng, 2009).

Figure 1. Sketch of experimental design for choice experiment.



2.4. Choice experiment

Preference of *D. porcellus* adults by the various yam landraces was evaluated in a choice experiment for delimiting an arena of a circular shape 18 cm in diameter on a cardboard, as described by Babajide et al. (2008). A 5 cm-radius circle was drawn at the center of the arena. The ring between the two circles was then divided into 24 equal parts (Figure 1). The cardboard was then placed in a tray of 18 cm diameter and glued to the floor of tray. In each compartment, a sample of 5 g of yam chips of each landrace was deposited equidistant from the center of the arena. Later, 25 starved (1 h of starvation) *D. porcellus* adults (48 h old) were released at the center of the arena, which was immediately covered with a transparent muslin cloth, in order to prevent the insects from escaping (Isah et al., 2009). The experiment was replicated at 3 different times with 3 replications (a total of 9 repetitions), each time with fresh individuals of *D. porcellus* and new yam chips (Onzo et al., 2015). The distribution of the insects in the arena was recorded at 1, 24 and 48 h after infestation (Babarinde et al., 2008).

2.5. Adult mortality and yam chips weight loss

In this experiment, 20 g of yam chips of each landrace were placed in circular plastic containers (4.5 cm height × 3 cm diameter) according to Issa, Afun, Mochiah, Owusu-Akyaw, and Braimah (2011) and Onzo et al. (2015). In each container, the yam chips were infested with 5 adults (48 h old) of mixed sex *D. porcellus*. These containers were covered with a perforated plastic lid with a hole covered by a muslin cloth to allow aeration and prevent escape of the insects. The plastic containers were placed in completely randomized design in the laboratory for 10, 20, 30, 60 and 90 days (Chukwulobe & Echezona, 2014; Isah, Sylvester, & Zakka, 2012). For each landrace and time, the treatment was replicated 3 times. At the end of each experimental period, the percentage of weight loss was calculated using the formula used by Chukwulobe and Echezona (2014), Zakka, Lale, Duru, and Ehisianya (2013) and Atijegbe, Lale, Zakka, Atuakpoho, and Ehisianya (2014):

$$\text{Percentage weight loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

The mortality rate of *D. porcellus* adults was calculated with data from observations of 10, 20 and 30 days after infestation, in order to avoid counting possible progeny of *D. porcellus*, using the formula:

$$\text{Mortality rate} = \frac{\text{Number of dead } D. \textit{porcellus}}{\text{Number of introduced } D. \textit{porcellus}} \times 100$$

2.6. Susceptibility index

For each landrace, 20 g of yam chips were packed in plastic containers (4.5 cm height × 3 cm diameter) and closed with muslin cloth to prevent escape. Samples in each container were infested with ten 2-day-old *D. porcellus* adults, in the proportion five females and five males. Insects were sexed by their genitalia according to Halstead (1963). Adults of *D. porcellus* were allowed to feed and oviposit for 7 days after which the insects were removed. The plastic containers were kept in the laboratory at 25 ± 2°C, 70 ± 5% R.H. and 12L/12D photoperiod (Oni & Omoniyi, 2012). Yam chips were checked for adult emergence 35 days after exposure (Oni & Omoniyi, 2012), 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 (Torres, Saavedra, Zanuncio, & Waquil, 1996). Treatment was replicated 4 times for each landrace. The index of susceptibility was calculated as given by the formula of Dobie (1974):

$$\text{Index of susceptibility} = \frac{\text{Log e total number of } F_1 \text{ progeny emerged}}{\text{Median development time}} \times 100$$

where the median development time was calculated as the time (days) from the middle of the oviposition period to the emergence of 50% of the F1 progeny (Dobie, 1977). A susceptibility index ranges from 0 to 11 was used to classify the yam chips from 24 landraces, where: 0 to 3 = resistant, 4 to 7 = moderately resistant, 8 to 10 = susceptible, and ≥11 = highly susceptible (Dobie, 1974).

2.7. Statistical analyses

Data on proportion of *D. porcellus* attracted by each yam landrace, percent adult mortality, weight loss were arcsine transformed, while data recorded on number of F1 progeny were log-transformed, in order to homogenize their variance. The transformed data were analysed using one-way ANOVA using the SPSS analysis software Version 17.0. Significant differences between means were separated using Student Newman Keuls test ($p < 0.05$). Back-transformed (original) data are presented in tables and figures.

3. Results

3.1. Choice of *D. porcellus* among various yam chips

The choice of *D. porcellus* among the different yam chips varied from one landrace to another. The percentage of *D. porcellus* that made a choice increased with exposure time from 81.33 to 93.78% between 1 and 48 h, respectively (Figure 1). However, there was no significant difference ($df = 71$; $F = 0.422$; $p = 0.657$) among the number of *D. porcellus* that made a choice between 1, 24 and 48 h. Similarly, the percent mortality number of *D. porcellus* did not change significantly ($df = 26$; $F = 0.029$; $p = 0.972$) with the duration of exposure.

In the choice experiment, the average number of *D. porcellus* found on each yam landrace varied from one landrace to another depending on the duration of the test (Table 2). After 1 h ($df = 215$; $F = 2.776$; $p = 0.000$) and 24 h ($df = 215$; $F = 2.235$; $p = 0.002$), *D. porcellus* displayed a strong preference for the landrace Kinkérékou (Table 2). After 48 h, the landraces Baniouré souan and Kokoro agbalé were significantly ($df = 215$; $F = 2.129$; $p = 0.003$) more preferred (Table 2). In general, significant differences ($df = 647$; $F = 5.810$; $p = 0.000$) in the distribution of *D. porcellus* on the yam chips from the 24 landraces were observed, with strongest preferences for the landraces Kinkérékou and Baniouré souan, while Ayé, Boniwouré and Wonmangou were the least preferred (Figure 2).

3.2. Mortality of *D. porcellus* on the chips of different yam landraces

Mortality levels of *D. porcellus* at 10 days after infestation varied significantly ($df = 71$; $F = 2.812$; $p = 0.001$) from one landrace to another (Table 3), with the highest values for Boniwouré

Table 2. Average number (\pm SE) of adults of *D. porcellus* attracted by yam chips of each 24 landraces after 1, 24 and 48 h exposure

Landraces	Mean number of <i>D. porcellus</i> attracted after		
	1 h	24 h	48 h
Agada bangahi	0.67 \pm 0.23abc A	0.44 \pm 0.33a A	0.44 \pm 0.24ab A
Alahina	0.56 \pm 0.17ab A	0.67 \pm 0.23a A	0.67 \pm 0.28ab A
Ayé	0.22 \pm 0.14a A	0.56 \pm 0.24a A	0.56 \pm 0.29ab A
Baniouré souan	2.00 \pm 0.40bc A	2.00 \pm 0.40ab A	2.00 \pm 0.33b A
Boniwouré	0.56 \pm 0.24ab A	0.44 \pm 0.17a A	0.22 \pm 0.14a A
Déba	0.44 \pm 0.24a A	1.11 \pm 0.38ab A	1.00 \pm 0.33ab A
Kinkérékou	2.11 \pm 0.30c A	2.33 \pm 0.40b A	1.44 \pm 0.33ab A
Gaboubaba	0.78 \pm 0.27abc A	0.44 \pm 0.24a A	0.67 \pm 0.33ab A
Gonopkèssa	1.22 \pm 0.32abc A	0.89 \pm 0.26ab A	0.89 \pm 0.30ab A
Kaagourou	1.00 \pm 0.33abc A	1.44 \pm 0.29ab A	1.78 \pm 0.40ab A
Kokoro agbalè	1.11 \pm 0.48abc A	1.44 \pm 0.41ab A	2.00 \pm 0.40b A
Kokoro lakolako	1.33 \pm 0.33abc A	1.00 \pm 0.37ab A	1.11 \pm 0.35ab A
Koriodjo	1.00 \pm 0.23abc A	0.89 \pm 0.30ab A	1.33 \pm 0.33ab A
Koumanan	0.56 \pm 0.24ab A	0.44 \pm 0.24a A	0.56 \pm 0.24ab A
Kounan	1.11 \pm 0.51abc A	1.00 \pm 0.37ab A	1.00 \pm 0.40ab A
Kourokourougouroko	0.67 \pm 0.28abc A	1.11 \pm 0.42ab A	1.22 \pm 0.40ab A
Omonya	0.89 \pm 0.42abc A	0.67 \pm 0.28a A	0.67 \pm 0.28ab A
Otoukpanan	0.44 \pm 0.17a A	0.89 \pm 0.38ab A	0.67 \pm 0.28ab A
Singor	0.67 \pm 0.37abc A	1.22 \pm 0.40ab A	1.33 \pm 0.50ab A
Singou	1.22 \pm 0.22abc A	0.67 \pm 0.33a A	0.78 \pm 0.27ab A
Souwoukou	0.22 \pm 0.22a A	1.00 \pm 0.37ab A	0.89 \pm 0.30ab A
Wonmangou	0.11 \pm 0.11a A	0.44 \pm 0.24a A	0.67 \pm 0.28ab A
Yakanougo	1.00 \pm 0.33abc A	0.67 \pm 0.16a A	0.56 \pm 0.24ab A
Yassou bagourou	0.44 \pm 0.17a A	1.11 \pm 0.78ab A	1.00 \pm 0.28ab A

Notes: Means within columns followed by the same lower-case letter, and means within rows followed by the same upper-case letter, are not significantly different ($p \geq 0.05$).

(46.67 \pm 24.0%) and Alahina (46.67 \pm 6.67%) landraces, and the lowest for Kounan and Singou landraces (Table 3). A similar trend ($df = 71$; $F = 2.799$; $p = 0.001$) was observed at 20 days after infestation with Boniwouré displaying the highest (53.33 \pm 17.63%) and Singou the lowest mortality rate (6.67 \pm 6.67%), respectively. At 30 days of infestation, only Boniwouré (80.00 \pm 0.00%) showed a significant mortality rate ($df = 71$; $F = 5.702$; $p = 0.000$) compared to the other landraces (Figure 3).

Figure 2. *D. porcellus* mortality and surviving population during attractiveness experiment.

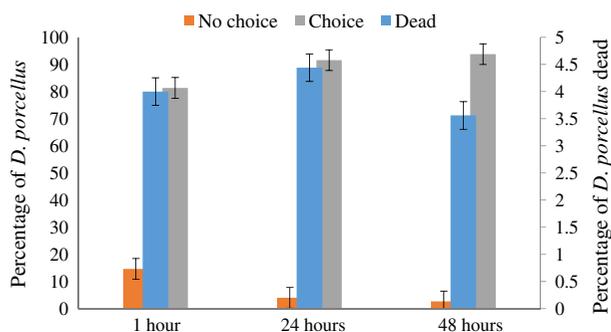


Table 3. Mean mortality (± SE) of *D. porcellus* feeding on the 24 different yam chips

Landraces	Mean mortality of insect after		
	10 days	20 days	30 days
Agada bangahi	6.67 ± 3.33ab	10.00 ± 5.77a	13.33 ± 3.33a
Ayé	16.67 ± 3.33abc	16.67 ± 3.33a	20.00 ± 0.00a
Baniouré souan	26.67 ± 3.33abc	26.67 ± 3.33a	26.67 ± 3.33a
Déba	13.33 ± 3.33abc	13.33 ± 3.33a	13.33 ± 3.33a
Kinkérékou	23.33 ± 6.67abc	23.33 ± 6.67a	23.33 ± 6.67a
Kokoro agbalè	10.00 ± 5.77abc	13.33 ± 3.33a	13.33 ± 3.33a
Kokoro lakolako	20.00 ± 5.77abc	20.00 ± 5.77a	23.33 ± 8.81a
Koriodjo	10.00 ± 5.77abc	10.00 ± 5.77a	13.33 ± 3.33a
Koumanan	23.33 ± 6.67abc	23.33 ± 6.67a	26.67 ± 8.81a
Kouroukourouoko	10.00 ± 0.00abc	13.33 ± 3.33a	13.33 ± 3.33a
Omonya	16.67 ± 3.33abc	20.00 ± 5.77a	20.00 ± 5.77a
Otoupkpanan	16.67 ± 8.81abc	16.67 ± 8.81a	20.00 ± 5.77a
Singor	10.00 ± 0.00abc	16.67 ± 3.33a	16.67 ± 3.33a
Souwoukou	13.33 ± 3.33abc	10.00 ± 0.00a	10.00 ± 0.00a
Wonmangou	10.00 ± 0.00abc	16.67 ± 3.33a	16.67 ± 3.33a
Yakanougo	10.00 ± 0.00abc	20.00 ± 5.77a	20.00 ± 5.77a
Yasssou bagarou	13.33 ± 3.33abc	16.67 ± 3.33a	16.67 ± 3.33a
Alahina	46.67 ± 6.67c	46.67 ± 6.67ab	46.67 ± 6.67a
Boniwouré	46.67 ± 24.03c	53.33 ± 17.63b	80.00 ± 0.00b
Gaboubaba	6.67 ± 6.67ab	40.00 ± 11.54ab	40.00 ± 11.54a
Gonopkèssa	40.00 ± 11.54bc	40.00 ± 11.54ab	40.00 ± 11.54a
Kaagourou	13.33 ± 13.33abc	20.00 ± 11.54a	20.00 ± 11.54a
Kouman	0.00 ± 0.00a	13.33 ± 6.67a	20.00 ± 11.54a
Singou	0.00 ± 0.00a	6.67 ± 6.67a	26.67 ± 13.33a

Note: Means within columns followed by the same lower-case letter are not significantly different ($p \geq 0.05$).

3.3. Evaluation of losses due to *D. porcellus*

Weight loss across the different yam landraces increased significantly with an increase of exposure time to *D. porcellus* except for the Kaagourou landrace (Table 4). At 10 days of exposure, Wonmangou landrace was significantly ($df = 71$; $F = 4.331$; $p = 0.000$) less attacked, whereas, Déba landrace was

Figure 3. Distribution of *D. porcellus* on the yam chips from the 24 landraces.

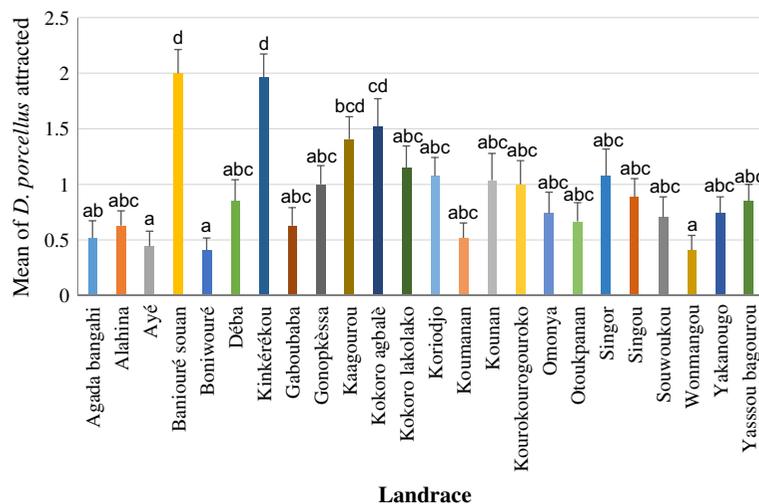


Table 4. Percentage weight loss (\pm SE) of the yam chips of the 24 landraces consumed by *D. porcellus*

Landraces	Mean proportion weight loss (%)				
	10 days	20 days	30 days	60 days	90 days
Agada bangahi	1.60 \pm 0.16abcd A	2.11 \pm 0.28a A	3.01 \pm 0.50abcd A	8.56 \pm 1.37bc B	15.78 \pm 1.29d C
Ayé	1.65 \pm 0.43abcd A	2.51 \pm 0.34a AB	2.66 \pm 0.57abcd AB	5.05 \pm 0.82ab B	8.80 \pm 0.82abc C
Baniouré souan	1.06 \pm 0.17abcd A	1.63 \pm 0.23a A	1.96 \pm 0.11ab A	4.48 \pm 0.46 ab B	6.16 \pm 1.19ab B
Déba	2.89 \pm 0.29e A	4.06 \pm 0.24a A	5.00 \pm 0.49bcd A	9.15 \pm 1.05bc B	10.90 \pm 2.00abcd B
Kinkérékou	1.18 \pm 0.27abcd A	2.25 \pm 0.57a A	2.55 \pm 0.45abc A	5.33 \pm 1.09ab AB	7.71 \pm 1.63ab B
Kokoro agbalè	0.83 \pm 0.26ab A	0.73 \pm 0.07a A	1.56 \pm 0.37a A	2.71 \pm 0.54a A	4.80 \pm 0.77a B
Kokoro lakolako	1.31 \pm 0.15abcd A	2.36 \pm 0.13a AB	2.60 \pm 0.37abc AB	6.13 \pm 1.49ab BC	7.06 \pm 1.76ab C
Koriodjo	2.40 \pm 0.47de A	3.51 \pm 0.56a A	5.35 \pm 0.45 cd A	10.83 \pm 1.21c B	14.40 \pm 2.52 cd B
Koumanan	1.50 \pm 0.02abcd A	2.30 \pm 0.15a A	2.38 \pm 0.23abc A	5.28 \pm 0.76ab B	9.18 \pm 1.30abc C
Kourokourogou-roko	1.51 \pm 0.47abcd A	2.13 \pm 0.56a A	2.91 \pm 0.58abcd A	5.51 \pm 0.58ab B	6.28 \pm 1.11ab B
Omonya	1.75 \pm 0.14bcd A	1.46 \pm 0.19a A	2.35 \pm 0.20abc A	5.48 \pm 0.83ab B	9.18 \pm 1.30abc C
Otoukpanan	1.25 \pm 0.23abcd A	1.78 \pm 0.29a A	2.40 \pm 0.51abc A	5.50 \pm 1.00ab A	9.71 \pm 2.04abc B
Singor	0.76 \pm 0.12ab A	1.01 \pm 0.14a A	1.76 \pm 0.10ab A	7.10 \pm 0.91abc B	16.08 \pm 3.79bcd C
Souwoukou	1.15 \pm 0.35abcd A	2.08 \pm 0.20a A	2.75 \pm 0.31abcd A	7.16 \pm 0.36abc B	11.13 \pm 1.63abcd C
Wonmangou	0.25 \pm 0.05a A	0.50 \pm 0.05a A	0.60 \pm 0.05a A	2.16 \pm 0.28a B	4.21 \pm 0.47a C
Yakanougo	1.08 \pm 0.45abcd A	1.68 \pm 0.46a AB	3.35 \pm 0.71abcd B	7.25 \pm 0.54abc C	9.03 \pm 0.42abc D
Yassou bagarou	0.90 \pm 0.14ab A	1.81 \pm 0.21a A	2.25 \pm 0.36abc A	6.23 \pm 0.83ab B	10.10 \pm 0.45abc C
Alahina	1.23 \pm 0.11abcd A	1.88 \pm 0.08a A	3.41 \pm 0.22bcd AB	4.75 \pm 0.92ab B	6.73 \pm 1.08ab C
Boniwouré	1.00 \pm 0.18abc A	1.41 \pm 0.24a A	2.15 \pm 0.25abcd AB	2.76 \pm 0.37a BC	3.46 \pm 0.47a C
Gaboubaba	1.45 \pm 0.12abcd A	2.18 \pm 0.29a A	3.31 \pm 0.26abcd AB	5.11 \pm 0.35ab B	7.46 \pm 1.30ab C
Gonopkèssa	1.38 \pm 0.10abcd A	2.00 \pm 0.00a A	3.41 \pm 0.23abcd B	4.68 \pm 0.37ab B	6.21 \pm 0.77ab C
Kaagourou	1.58 \pm 0.30abcd A	3.50 \pm 1.87a A	5.60 \pm 2.27d A	6.76 \pm 2.71abc A	7.86 \pm 2.87ab A
Kounan	1.26 \pm 0.17abcd A	1.86 \pm 0.20a A	3.36 \pm 0.30abcd B	3.96 \pm 0.09ab B	5.91 \pm 0.56ab C
Singou	2.35 \pm 0.30cde A	6.05 \pm 2.40b A	3.88 \pm 2.26abcd A	5.74 \pm 0.28ab A	7.70 \pm 0.57ab A

Notes: Means within columns followed by the same lower-case letter, and means within rows followed by the same upper-case letter, are not significantly different ($p \geq 0.05$).

the most consumed (Table 4). A similar trend was observed after 20 days of exposure ($df = 71$; $F = 2.731$; $p = 0.002$) with Wonmangou being the least (0.50 ± 0.05) and Singou the most attacked (6.05 ± 2.40), respectively. After 30 ($df = 71$; $F = 3.585$; $p = 0.000$) and 60 days of exposure ($df = 71$; $F = 4.341$; $p = 0.000$), Kokoro Agbalè and Wonmangou were significantly the least attacked, respectively (Table 4). At 90 days after infestation, Boniwouré, Wonmangou, and Kokoro Agbalè was significantly less attacked ($df = 71$; $F = 4.766$; $p = 0.000$), while Agada bangahi incurred the highest weight losses (Table 4).

3.3.1. *D. porcellus* progeny emergence and yam landrace index of susceptibility

Overall, significant differences ($df = 23$; $F = 16.878$; $p = 0.000$) were observed with regard to *D. porcellus* progeny emergence (Table 5). Kinkérékou displayed the highest progeny (190.00 ± 6.48) followed by Agada bangahi (182.25 ± 22.80), while Gaboubaba had the least progeny (2.25 ± 0.62). The median developmental time of *D. porcellus* varied significantly ($df = 23$; $F = 36.35$; $p = 0.000$) from 36.91 days for Déba landrace to 42.91 days for Yakanougo landrace (Table 5). The index of susceptibility ranged from 0.88 to 5.97 for Gaboubaba and Agada bangahi, respectively (Table 5). Only 5 landraces (Gaboubaba, Boniwouré, Alahina, Yakanougo, Wonmangou) were rated as resistant, while all the remaining ones were moderately resistant to *D. porcellus* attack.

Table 5. Number of emerged F₁ progeny, median development time of *D. porcellus*, susceptibility index of yam chips of 24 landraces and resistance category

Yam landraces	Number of F ₁ progeny emerged	Median development time (days)	Susceptibility index	Resistance category
Agada bangahi	182.25 ± 22.80 h	37.88 ± 0.23 ab	5.97	Moderately resistant
Ayé	60.50 ± 9.57 cdefg	37.86 ± 0.73 ab	4.71	Moderately resistant
Baniouré souan	95.00 ± 25.75 defgh	37.95 ± 0.36 ab	5.21	Moderately resistant
Déba	73.25 ± 11.73 defgh	36.91 ± 0.82 a	5.05	Moderately resistant
Kinkérékou	190.00 ± 6.48 h	39.47 ± 0.41 abcd	5.77	Moderately resistant
Kokoro agbalè	119.00 ± 13.80 fgh	38.07 ± 0.55 ab	5.45	Moderately resistant
Kokoro lakolako	72.50 ± 23.36 cdefg	39.91 ± 0.76 abcd	4.66	Moderately resistant
Koriodjo	60.75 ± 13.41 cdefg	41.03 ± 0.37 abcd	4.35	Moderately resistant
Koumanan	108.25 ± 17.70 efgh	39.80 ± 0.45 abcd	5.11	Moderately resistant
Kourokourougouroko	112.50 ± 11.18 fgh	39.20 ± 0.41 abcd	5.23	Moderately resistant
Omonya	73.25 ± 10.45 defgh	40.32 ± 0.68 abcd	4.63	Moderately resistant
Otoutkpanan	98.25 ± 7.42 efgh	37.77 ± 0.55 ab	5.27	Moderately resistant
Singor	130.75 ± 16.66 gh	40.39 ± 0.57 abcd	5.24	Moderately resistant
Souwoukou	92.25 ± 13.19 efgh	39.40 ± 0.97 abcd	4.99	Moderately Resistant
Wonmangou	40.00 ± 8.38 bcde	41.54 ± 1.22 bcd	3.86	Resistant
Yakanougo	29.50 ± 10.27 bc	42.91 ± 0.85 d	3.43	Resistant
Yassou bagarou	60.00 ± 14.12 cdefg	40.41 ± 1.05 abcd	4.40	Moderately resistant

Note: Values with the same letters in the same column are not significantly different ($p > 0.05$).

4. Discussion

In the free choice condition, *D. porcellus* was more attracted by the chips from the landraces Baniouré souan, and Kinkérékou than those of the others. These results coincide with findings by Onzo et al. (2015) who showed that there is a differential attraction of *D. porcellus* with respect to chips from four different yam landraces (Otoutkpanan, Singor, Kprakpra and Portchahabim) from Benin. This difference in choice of chips by the pest could be explained by the fact that, although dried, different landraces influence *D. porcellus* through physicochemical characteristics such as colour, smell or texture, that may be repulsive or attractive to the pest. Indeed, colour and physical properties of dried yam may be affected by the landrace (Aki-soé, Hounhouigan, Mestres, & Nago, 2003) and by the drying method (Hsu, Chen, Weng, & Tseng, 2003).

Observed *D. porcellus* mortality in chips of the different yam landraces were significantly different. Boniwouré landrace showed significant mortality of *D. porcellus*. Pest mortality can be explained by the fact that several chemical compounds found in plants can exert insecticidal and repellent effects inhibiting the development of storage insects (Hatil, 2009). Studies conducted by Lale (2002) showed that, the soluble tannins and phenols contained, for example in corn, sorghum and millet cause adult mortality of storage pest such as *Sitophilus oryzae* L., *S. zeamais* Motschulsky and *Sitotroga cerealella* Olivier. Given that, resistant varieties are known to affect a cumulative reduction of pest and form a key component in all pest management programs (Lale, 2002), the Boniwouré landrace remains promising with respect to resistance to *D. porcellus*.

Despite the preference of *D. porcellus* for the landraces Baniouré souan and Kinkérékou, the ones that had the most significant losses were the landraces Singor and Agada bangahi. The composition of anti-nutritional factors would influence the consumption of each landrace by *D. porcellus* because, there is a difference between the yam landraces in terms of quantities of polyphenolic compounds (e.g. tannins), alkaloids (e.g. dioscorine), steroid derivatives (e.g. diosgenin), crystals of calcium oxalate and phytic acid (Polycarp, Afoakwa, Budu, & Otoo, 2012). Studies conducted by

Osipitan, Sangowusi, Lawal, and Popoola (2015) and Popoola, Opayele, and Nkpondion (2015) on the resistance of cassava chips *Prostephanus truncatus* (Horn), pest belonging to the same family of *D. porcellus*, revealed that the differential resistance of landraces to this pest was conferred by secondary metabolites such as tannins, saponins, alkaloids, and the hydrocyanic acid content. According to previous researches, chips loss rate due to storage insects also depends on a number of factors including: chips texture (Campbell & Runnion, 2003), a partial starch gelatinization following the pre-cooking, which causes hardening of chips (Rajamma et al., 1996) the biochemical composition of chips (nutrients and anti-nutrients), which could encourage or discourage survival and multiplication of pests (Wong & Lee, 2011), in addition to environmental conditions (temperature, humidity, etc.) (Chukwulobe & Echezona, 2014). The biochemical composition of the Boniwouré and Wonmangou landraces should finally be investigated to determine which anti-nutritional factors are behind its low attractiveness and low loss rate with respect to *D. porcellus*.

A resistant yam landrace is expected to have relatively lower number of adult progenies than a susceptible landrace (Onzo et al., 2015). Lowest number of emerged *D. porcellus* adults, indicating that Gaboubaba landrace was less susceptible to *D. porcellus* attack. The higher mean of insect development period in landrace Yakanougo indicate the expression of antibiosis, characterized by a delayed larval cycle or larval development interruption (Lara, 1991). According to Zakka et al. (2013) the presence of phenolic compounds and saponins (secondary metabolites) in yams may confer antibiosis against developing stages of storage insect.

Among the chips of the 24 yam landraces evaluated, only Gaboubaba, Boniwouré, Alahina, Yakanougo, Wonmangou were regarded as resistant, while all the remaining landraces were categorized as moderately resistant to *D. porcellus* attack. These variations in the differential susceptibility of chips from the different yam landraces show the innate capacity of a particular landrace to resist *D. porcellus* attack. Resistant yam landraces exhibited low attractiveness of pest, minimum weight loss, high mortality of pest, reduced multiplication of F1 progeny, longer median developmental period and lower score of susceptibility index. These resistant yam landraces can reduce the cost of *D. porcellus* management and the resistance can also be utilized as an environmental friendly way to reduce damage by this pest.

5. Conclusion

This study indicated varietal differences in response of yam chips to damage by *D. porcellus*. From our results that chips from the Baniouré souan and Kinkérékou landraces exert a strong attraction on *D. porcellus* than chips from other landraces. Losses caused by *D. porcellus* were higher on chips from the Singor and Agada bangahi landraces. With less attractiveness, lower weight loss, lower F1 progenies emergency, lower indices of susceptibility, higher adult mortality and longer median development period, the Boniwouré, Gaboubaba, Alahina, Yakanougo and Wonmangou landraces were resistant to *D. porcellus* attack, while others were categorized as moderately resistant. The chips of these resistant yam landraces can be stored for longer periods of time under traditional storage system of small-scale farmers with reduced threat of *D. porcellus*, reduced cost of pest management and no adverse effect on the environment. Thus, it is important to include these resistant landraces in the production system of yam meant for chips production.

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