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Relative Susceptibility of Dried Root/Tuber and Musa Chips to Red Flour Beetle (*Tribolium casteneum*) (Herbst) (*Coleoptera: Tenebrionidae*) Infestation

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Authors' contributions

This work was carried out in collaboration between all authors. Author BCE designed the study. Author MNC carried out the laboratory work and managed the literature searches. Authors MNC and BCE managed the statistical analyses. Author MNC wrote the first draft of the manuscript and all authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Three *Musa* cultivars (false horn, french, and cooking banana) and eight roots/tubers (*Colocasia esculenta*, *C. esculenta* var *antiquorum*, *Xanthosoma sagittifolium, Dioscorea alata, D. dumentorum, D. rotundata*, sweet cassava and bitter cassava) were assayed for their relative susceptibility to flour beetle (*Tribolium casteneum* Herbst.) (*Coleoptera: Tenebrionidae*) damage. Ten adult beetles (1- 7 days old) (5 males: 5 females) were introduced in containers to which 20 g of each dried chip sample was placed and arranged in completely randomised design with three replications. Susceptibility assessment was based on rate of chip damaged, percentage weight loss and adult survival, weight of powder produced and chips left. Bioassay on chips proximate, mineral and anti-nutrient compositions was also carried out. Rate of damage was higher amongst the agbagba (20.04 mg/day) compared to other *Musa* spp. Bitter cassava recorded the highest damage rate of 24.32 mg/day amongst the chips assayed, which was also higher than other cassava cultivars. *X. sagittiffolium* (5.57mg/day) and *C. esculenta* var *antiquorum* (6.14 mg/day) maintained higher rates of damage relative to *C. esculenta*

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(1.13 mg/day) in cocoyams. On yams, damage rate was significantly ($p<0.05$) higher on *D. rotundata* (12.24mg/day) compared to *D. dumentorum* (2.24mg/day) and *D. alata* (1.43) mg/day. Correlation and biplot analyses showed that though the susceptibility of bitter cassava to the pest attack was strong, it could not be tied to the biochemical contents analysed. Conversely, the resistance of *C. esculenta* was attributed to its strong and positive relationships to phenol, tannin, calcium and Fe. This result provides baseline information for breeders against stored produce pests.

Keywords: *Beetles; biochemicals; resistance; storage pest; stored produce.*

1. INTRODUCTION

It is no gain saying that safe keep of farm produce is as important as their production. According to Narong [1], it is misleading to measure productivity at the point of production rather than at the point of consumption. *Musa* spp and root/tuber crops are among the major food crops in the humid and sub-humid parts of Africa and a major source of energy for millions of people in these regions [2]. Post harvest losses constitute major problems limiting their availability in most producing regions of Sub-saharan Africa [3]. These losses are essentially associated with incorrect systems including harvesting, transportation, packaging and storage techniques [4,5]. Although recent researches have evolved methods of storing fresh produce, they are still under trial and have kept these produce for a few days [6]. *Musa* and roots/tubers can only be stored for a relatively long period of time in the form of dried chips or fried [7]. Processing crops to chips helps to increase their shelf life, reduce transport cost by reducing bulkiness, improve handling quality, remove non-edible and unmarketable parts and make producers earn higher income by helping them keep their produce till the season of scarcity [8]. Raw materials are also made available for the agro-industries [9]. Despite the above advantages, storage of chips have been faced with the problem of pests and moulds [10,3]. Dry stored products are attacked by many pests that cause serious damages to the products. It is necessary therefore to render proper importance to such pests, since cares and expenditures for pest control in field crops would be of no use if the products will be attacked and damaged when stored. The reduction of post harvest food losses is therefore a complementary means of increasing food production. In fact, it will be unreasonable to produce a crop if it cannot be kept safe until consumption protected from pest till consumed.

The red flour beetle, *Tribolium castaneum* is one of the primary pests infesting dry stored produce worldwide [11]. Infestations cause significant losses due to direct consumption of produce, reduction of nutrients and increase in temperature and moisture conditions that lead to accelerated growth of molds, including toxigenic species [10]. The adults are long lived and may live for more than three years [12]. They have high rate of population increase because the adult female can lay large number of viable eggs throughout their life [13,14]. Because of the great economic importance of this pest, many studies and researches have been going on for its control. Currently, different kinds of preventive and curative control measures are being tried. Among these, chemical pesticides have been used for a long time with some measure of success but with serious setbacks [15,16]. These setbacks include; pest resistance and resurgence, residue in food and feed, expensive to small-scale farmers [17]. It has been estimated that only about 0.1% of the agrochemicals used in crop protection reach the target pest leaving the remaining 99.9% to enter the environment to cause hazards to non-target organisms including humans [18].

Over the past 50 years, more than 2,000 plant species belonging to different families and genera have been reported to contain toxic principles which are effective against insects [19]. Numerous defensive chemicals belonging to various categories (alkaloids, glycosides, tannins, proteic amino acids, steroids, phenols, flavonoids, glucosinolates, quinones, terpenoids etc.), which have behavioural and physiological effects on pests have already been identified [20]. The deleterious effects of these plant compounds on insects can be manifested in several ways including toxicity, mortality, feeding deterrent, growth inhibition, suppression of reproductive behaviour and reduction of fecundity and fertility [21,22]. Plants are thus not helpless when confronted with insects and other pests. Potenza et al, [19] stated that right combinations of anti-nutrients possess protective functions against pests.

The objective of this work is to evaluate the relative susceptibility of different roots/tubers and *Musa* spp to *T. castaneum* and to identify the biochemical basis for their susceptibility/resistance.

2. MATERIALS AND METHODS

The study was carried out at the Department of Crop Science Research Laboratory, University of Nigeria, Nsukka (06º52' N, 07º24' E; 447.26m a.s.l.), Nigeria from February to May, 2012

Musa spp and root/tubers used for this study were procured from the markets around Nsukka and processed into chips. The sweet cassava variety was procured from Kwararafa new market in Jos, Plateau state of Nigeria.

The crops processed for chips were: *Musa spp.*(Linnaeus,Colla) namely: false horn (*Agbagba*); french (*Obino'l Ewai*); cooking banana (*Bluggoe*), while the root and tuber crops were: sweet cassava (*Manihot esculenta* Crantz); bitter cassava (*Manihot esculenta* Crantz); cocoyam (*Xanthosoma sagittifollium* Schott); cocoyam (*Colocasia esculenta* Schott); cocoyam, *ugwuta*; (*Colocasia esculenta var.antiquorum* Schott); white yam (*Dioscorea rotundata* Poir); Water yam (*Dioscorea alata* L.) and three-leaved yam (*Dioscorea dumentorum* Pax*)*

The plantain and cooking banana fingers used were collected from the second to fourth hand of a fully mature (round full maturity stage) but unripe bunch (Baiyeri, 2001 and 2004). The fingers were washed, peeled and cut into small round pieces under water and sun dried for one week. Cassava tubers were washed, peeled, cut and soaked in water to ferment for 48 hrs. Thereafter they were sun dried for 7days (Diop, 1998). Yams were peeled, cut into small pieces under water and washed in boiled water before being dried under the sun for about 5-7 days as modified from Eze, (1992) and Food Information Net. (2009). Cocoyam was boiled for about 30 minutes, cut into small pieces and sun dried for about 7 days. The processing was done during the dry season from January to April and the chips stored in air-tight containers at room temperature (27-30ºC) and relative humidity (75±5%) until they were used.

3. *Tribolium castaneum* (HERBST) CULTURE

Adult *Tribolium castaneum* was obtained from stock reared in plastic containers (2000 mls) in the Dept of Crop Science Teaching Laboratory of the University of Nigeria Nsukka. These were maintained in wheat flour with brewers yeast (19:1) at an ambient temperature and relative humidity of 27±3ºC and 75±5% respectively. The *T. castaneum* used were sexed as pupa by examining their external genital lobe or papillae, under a light microscope. The genital lobes are two finger-like structures (papillae) just anterior to the pointed urogomphi.This papillae are much larger, longer and prominent in females while they appear like finger tips in males [23]. Males and females were kept separately in plastic containers until they were used. The containers were covered with muslin cloth for aeration and to prevent the escape of the insects.

4. EVALUATION OF THE SUSCEPTIBILITY OF DIFFERENT CHIPS to *T. Castaneum*

Twenty grammes of each type of the chips was weighed out into plastic containers after further drying to constant weight and moisture in the oven. The plastic containers were perforated by the sides (about 3.5cm diameter) and sealed with muslin cloth for proper aeration and to prevent escape of the pest. Ten adult *T. castaneum,* comprising 5 males and 5 females (1 - 7days old) were introduced into each container. The experiment was arranged in a completely randomised design (CRD) manner with three replications on the laboratory bench. The following records were taken:

i) weight of chips before infestation.
ii) survival count of beetles on the 7^{th}, 14^{th} and 21^{st} day after infestation.
iii) total no of live adult produced after 91 days of infestation.
iv) weight of powder produced after 91 days of infestation.
v) weight of chips left after 91 days of infestation.
vi) From these records, the following computations were made:

1) Percentage survival:

$$\frac{\text{Number of live beetles}}{\text{Number introduced}} \times \frac{100}{1}$$

2) Percentage weight loss by chips:

$$\frac{\text{Weight lost}}{\text{Initial weight}} \times \frac{100}{1}, \text{ and}$$

3) Rate of damage was calculated by dividing the weight lost by the storage time.

5. BIOCHEMICAL ANALYSIS OF THE CHIPS

Chemical analysis of the various chips used was carried out in the Department of Crop Science Analytical Laboratory, University of Nigeria Nsukka. This was performed on ground sun dried samples according to the Official and Standard method of Analysis [24].

The plant chips were analysed for moisture, ash, total protein, crude fat, carbohydrates, crude fibres, minerals (Calcium, Magnesium, Phosphorus, Iron, sodium, Potassium, Zinc) and for anti-nutrients (phenolic compounds, tannins, flavonoids, saponins and alkaloids).

Data obtained were subjected to analysis of variance (ANOVA) using Genstat System for Window Version 8 after the data were normalised where necessary by using appropriate transformation procedure. Differences amongst treatment means were separated using Duncan's New Multiples Range Test (DNMRT) as outlined by Gomez and Gomez [25]. GGE biplot analysis was invoked to delineate the discriminating ability and representativeness of the test chips to the damage assessing parameters. Thereafter correlation analysis was done using SPSS model version 16.

6. RESULTS

6.1 Susceptibility of Different Chips to *T. Castaneum*

6.1.1 Adult survival on various chips

There was no significant difference among the various chips in the survival of adult beetles on the 7th and 14th days after infestation (Table 1). On the 21st day after infestation, cooking banana, *obino'l* and sweet cassava each still maintained 100% adult survival. This was statistically similar to the percentage survival in *agbagba* (96.67%), bitter cassava (93.30%) and *D. rotundata* (93.30%) but were significantly (p<0.05) higher than the survival in other chips. *C. esculenta* however, recorded the least survival (10.00%) which was similar to *D. alata* (16.70%).

Table 1. Mean per cent survival of adult *T. castaneum* on various plant chips on 7th, 14th and 21st days after introduction

Chips	Day 7	Day 14	Day 21
Agbagba	96.67 (9.85)*a*	96.67 (9.85)*e*	96.67 (9.85)*f*
Cooking banana	100.00 (10.02)*a*	100.00 (10.02)*d*	100.00 (10.02)*g*
Obino'l Ewai	100.00 (10.02)*a*	100.00 (10.02)*d*	100.00 (10.02)*g*
Sweet cassava	100.00 (10.02)*a*	100.00 (10.02)*d*	100.00 (10.02)*g*
Bitter cassava	96.67 (9.85)*a*	93.30 (9.67)*c*	93.30 (9.67)*e*
C. esculenta	100.00 (10.02)*a*	73.30 (8.53)*a*	10.00 (2.83)*a*
X. sagittifollium	100.00 (10.02)*a*	100.00 (10.02)*d*	70.00 (8.40)*d*
C. esculenta var antiqorum (Ugwuta)	96.67 (9.85)*a*	96.67 (9.85)*e*	40.00 (6.33)*c*
Dioscorea alata	100.00 (10.02)*a*	90.00 (9.50)*b*	16.70 (4.00)*b*
D. dumentorum	100.00 (10.02)*a*	100.00 (10.02)	63.30 (7.97)*c*
D. rotundata	100.00 (10.02)*a*	96.67 (9.85)*e*	93.30 (9.68)*e*
Mean	99.09 (9.97)	95.20 (9.76)	71.20 (8.07)

Means followed by the same letter in the same column do not differ significantly according to Duncan's New Multiple Range Tests (p<0.05). Numbers in parentheses are square root transformed values to which F-LSD was applied. Ns=Not significant

6.1.2 Damage assessment of chips exposed to *T. Castaneum*

Beetle counts taken 91 days after infestation vary significantly (p < 0.05) among various chips (Table 2). The highest number (11.67) was observed in *Obino'l* which was statistically similar to bitter cassava (11.33), *D. rotundata* (10.33), *Agbagba* (10.33), cooking banana (9.33) and sweet cassava (10.33). These were significantly higher than the number in other chips. The least number was found in *C. esculenta* (0.00). *D. alata* and *C. esculenta* chips retained the highest weight (19.87g each) at the end of the sampling period. This weight was statistically similar to the weight of *X. sagittifollium* (19.49g), *ugwuta* (19.44g), *D. dumentorum* (19.80g) and *D. rotundata* (18.89g), but was however significantly (p < 0.05) higher than other chips. Bitter cassava had the least weight of 17.79g. Powder production was inversely related to weight loss. Bitter cassava produced the highest powder (1.30g), which was significantly (p < 0.05) higher than other those of other chips. *C. esculenta* however had the lowest powder weight (0.00 g). Bitter cassava (11.07%) recorded significantly higher weight loss than other chips while *C. esculenta* chips had the least weight loss (0.63%), which was similar to the loss sustained by *D. alata* chips (0.65%). Rate of damage followed the same trend as the weight loss with bitter cassava having significantly (p< 0.05) higher rate of damage than the rest of the chips.

Table 2. Damage assay of various chips exposed to *T. castaneum* 91 days after infestation

Chips	Mean number of adult beetle found	Mean weight of chips left (g)	Mean weight of powder produced (g)	Mean % weight loss	Mean rate of damage (mg/day)
Agbagba	10.33 (3.29)*h*	18.18 (4.32)*b*	0.82 (1.15)*g*	9.12 (3.09)*i*	20.04 (4.52)*g*
Cooking banana	9.33 (3.13)*g*	18.58 (4.37)*d*	0.85 (1.16)*g*	7.08 (2.75)*g*	15.57 (4.00)*e*
Obino'l Ewai	11.67 (3.48)*i*	18.27 (4.33)*c*	0.96 (1.21)*h*	8.67 (3.02)*h*	19.05 (4.41)*f*
Sweet cassava	10.33 (3.29)*h*	18.62 (4.37)*d*	0.44 (0.97)*f*	6.90 (2.72)*f*	15.16 (3.95)*e*
Bitter cassava	11.33 (3.44)*i*	17.79 (4.28)*a*	1.30 (1.34)*i*	11.07 (3.40)*j*	24.32 (5.64)*h*
C. esculentia	0.00 (0.71)*a*	19.87 (4.52)*j*	0.00 (0.71)*a*	0.63 (1.06)*a*	1.39 (1.37)*a*
X. sagittifollium	5.67 (2.47)*e*	19.49 (4.47)*h*	0.22 (0.85)*d*	2.53 (1.74)*b*	5.57 (2.45)*b*
C. esculenta var antiqorum (ugwuta)	3.00 (1.86)*d*	19.44 (4.47)*g*	0.08 (0.75)*c*	2.82 (1.81)*c*	6.19 (2.57)*b*
Dioscorea alata	1.00 (1.10)*b*	19.87 (4.52)*j*	0.01 (0.71)*b*	0.65 (1.07)*a*	1.43 (1.39)*a*
D. dumenthorum	2.00 (1.58)*c*	19.80 (4.51)*i*	0.16 (0.81)*d*	1.02 (1.23)*b*	2.24 (1.65)*a*
D. rotundata	10.33 (3.29)*h*	18.89 (4.40)*e*	0.36 (0.93)*e*	5.57 (2.46)*d*	12.24 (3.57)*c*

Means followed by the same letter in the same column do not differ significantly according to Duncan's New Multiple Range Tests (p<0.05). Numbers in parentheses are square root transformed values to which F-LSD was applied.

6.1.3 Biplot analysis of various chips by damage assessing parameters

The biplot explained 99.2% (96% + 3.20%) of the total variation in damage due to differences in types of chips (Fig. 1). Bitter cassava chips (Bc) were the most susceptible to attack and thereby recorded the highest percentage weight loss (PWL), produced the highest powder (WOP), recorded the highest number of beetles (NAB) and the highest rate of damage (ROD) than other chips. Bc chips susceptibility was followed by that of *Musa* spp (Ab, Cb, Oe). Chips of *Colocasia esculenta* (Ce), *D. alata* (Da) and *D. dumentorum* (Dd) appeared on the reverse side of the biplot sector where Bc is the vertex chips and where weight of chips left after the storage period (WOC) falls. That means they had lower weight loss, lower rate of damage, lower weight of powder produced than Bc, but retained higher weight at the end of the storage time. Bc, Ce and Dr which appeared at the vertex of the polygon are referred to as vertex chips and therefore these chips are highly divergent in their reaction to attack by the beetles than others.

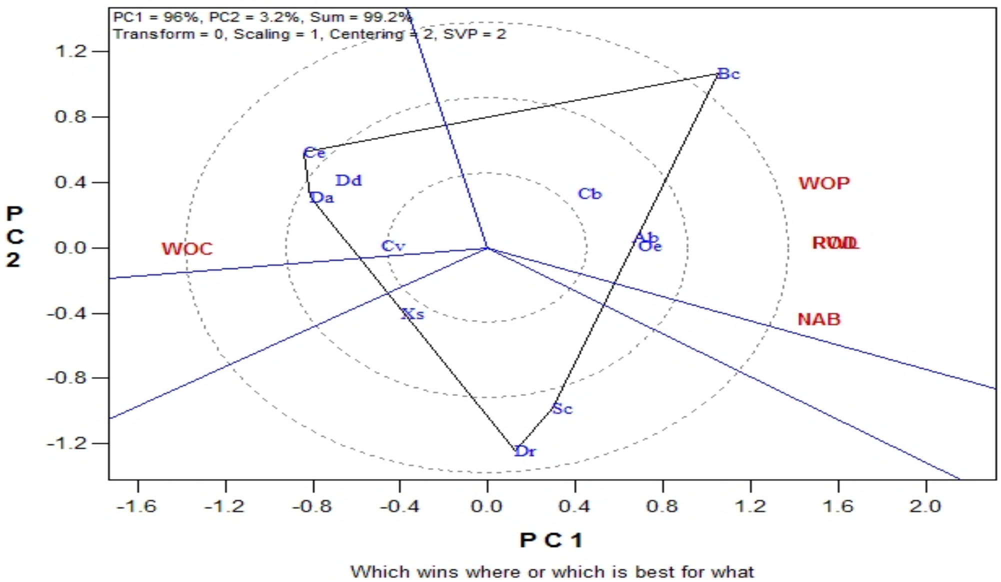

Fig. 1. Biplot of chips types by damage parameters

Ab = Agbagba, Cb = Cooking banana, Oe = Obino'l ewai, Da = Dioscorea alata, Dr = D. rotundata, Dd = D. dumentorum, Sc = Sweet cassava, Bc = bitter cassava, Ce = Colocasia esculenta, Cv = Colocasia esculenta var antiquorum, Xs = Xanthosoma sagittiffolium, WOC = weight of chips, WOP = weight of powder, NAB = Number of adult beetles, ROD = Rate of damage, PWL = Percentage weight loss.

Fig. 2 showed that ROD and PWL were better indices or parameters for assessing damage caused by *T. castaneum* in various chips than other parameters measured while *agbagba* and *obino'l* were good representative of all chips with higher ROD, PWL, WOP and NAB (highly susceptible). WOC on the reverse side was a better index of assessing resistance in chips while Cv was a good representative of all resistant chips with high WOC. Thus, WOC, PWL and ROD are ideal parameters which connote susceptibility or resistance as the case may be, while Cv, Ab and Oe are ideal chips representing resistant or susceptible chips. These therefore appeared very close to the line at the centre of the concentric circles (from 0.0 on PC 2 to the opposite end).

6.1.4 Biochemical analysis of various chips used

6.1.4.1 Proximate composition of chips

High carbohydrates and dry matter contents were found among the various chips while the fat content was very minimal (Table 3). The three *Musa* chips had statistically similar carbohydrate content, which was also similar to that of sweet cassava, bitter cassava and *X. sagittifolium.* Chips of *D. dumentorum* however had the lowest carbohydrate content (Table 3). The protein content of all the chips analysed differed significantly from one another. *Agbagba* recorded the highest protein content (3.50%) while cooking banana had the lowest (2.98%). Fibre content was generally low among various chips. *D. dumentorum* however gave the highest fibre (2.00%). This was significantly higher than all the fibre contents of chips analysed. The lowest was found in *C. esculenta* var *esculenta* and sweet cassava. Ash was highest in *C. esculenta* chips and this was significantly higher than the ash contents of all the chips analysed. The lowest was observed in *Obino'l* and bitter cassava chips.

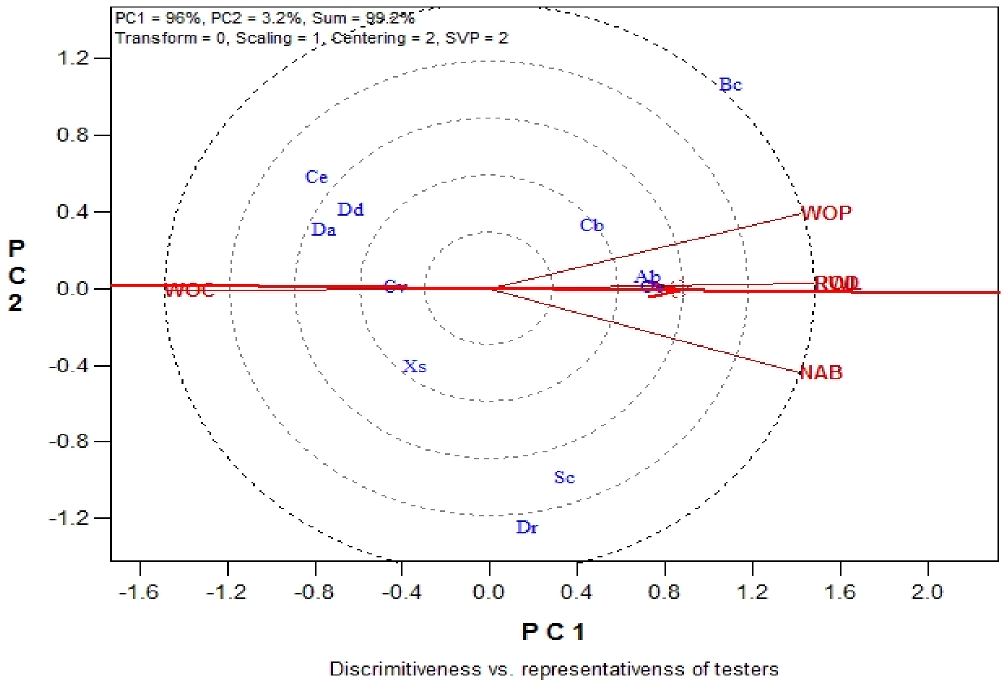

Fig. 2. Discrimination and representativeness view of the biplot (fig.1) to show the discriminating ability and representativeness of the test chips and the damage assessing parameters

Ab = Agbagba, Cb = Cooking banana, Oe = Obino'l ewai, Da = Dioscorea alata, Dr = D. rotundata, Dd = D. dumentorum, Sc = Sweet cassava, Bc = Bitter cassava, Ce = Colocasia esculenta, Cv = Colocasia esculenta var antiquorum, Xs = Xanthosoma sagittiffolium, WOC = weight of chips, WOP = weight of powder, NAB = Number of adult beetles, ROD = Rate of damage, PWL = percentage weight loss.

6.1.4.2 Anti-nutrient composition of various chips

Results of anti-nutrient analysis presented in table 4 showed that there was significant variation in alkaloid, flavonoid, tannin, phenol, and saponin contents of various chips tested. All the chips have high alkaloid contents with *agbagba* having the highest content of 8.18 mg/100 g. This was significantly ($p<0.05$) higher than the alkaloid contents of all other chips analysed while *D rotundata* had lowest alkaloid content. Flavonoid contents also varied significantly among chips except *obino'l*, sweet cassava, bitter cassava, *D*. *alata* and *D*. *Dumentorum,* which had significantly similar contents of flavonoid. Tannin content was generally low compared to alkaloid and flavonoid but also varied significantly among the various chips. The highest tannin was observed in *D*. *dumentorun* chips which was significantly ($p < 0.05$) higher than the content in all other chips. The lowest however, was found in *D*. *rotundata* chips. There was also significant variation in the phenol and saponin content of the chips used. *C*. *esculenta* had the highest phenol and saponin contents. These were significantly ($p < 0.05$) higher than the content in all other chips.

Table 4. Anti nutrients composition of various chips used (mg/100g).

Chips	Alkaloid	Flavonoid	Tannin	Phenol	Saponin
Agbagba	6.50*c*	4.74*f*	0.82*d*	0.61*b*	0.12*b*
Cooking banana	8.18*f*	2.47*e*	0.66*b*	1.48*f*	0.26*e*
Obino'l Ewai	8.13*e*	1.85*d*	0.78*c*	1.23*e*	0.20*cd*
Sweet cassava	7.32*d*	1.85*d*	0.98*e*	1.52*g*	0.18*c*
Bitter cassava	6.50*c*	1.85*d*	0.86*d*	1.15*d*	0.32*f*
C. esculenta	5.69*b*	0.68*b*	1.27*g*	2.36*k*	0.59*g*
X. sagittifollium	5.69*b*	0.62*a*	0.74*c*	1.00*c*	0.07*a*
C. esculenta var antiqorum (ugwuta)	7.32*d*	2.47*e*	1.11*f*	1.82*i*	0.21*d*
Dioscorea alata	8.13*e*	1.85*d*	1.23*g*	1.66*g*	0.15*c*
D. dumentorum	8.13*e*	1.85*d*	1.31*h*	1.89*j*	0.30*f*
D. rotundata	4.88*a*	1.23*c*	0.61*a*	0.45*a*	0.11*b*

Means followed by the same letter in the same column do not differ significantly according to Duncan's New Multiple Range Tests (p < 0.05).

6.1.5 Biplot analysis of chips type by anti-nutrient composition

Fig. 3 showed the variety by anti-nutrient biplot analysis of various chips. This biplot explained 79.3% (51.6%+27.7 %) of the total variation in the anti-nutrient content of chips due to varietal differences. *C. esculenta* (Ce), *D. dumentorum* (Dd), *Agbagba* (Ab) and *D. rotundata* (Dr) were most highly divergent from one another in their anti-nutrient contents. This was why they appeared at the vertexes of the polygon formed and are referred to as vertex chips. *C. esculenta* was highly influenced by its tannin, phenol and saponin contents while *D. dumentorum* and *D. alata* (Da) were both mostly influenced by their alkaloid content. Sweet cassava (Sc), bitter cassava (Bc), *obino'l ewai* (Oe), cooking banana (Cb) and *C. esculenta* var *antiqorum* (Cv) have little effect of the various anti-nutrients. Thus, they appeared close to the point at the centre of the biplot. *D. rotundata* had the least influence of the anti-nutrients so appeared at the section of the biplot with no anti-nutrient.

6.1.5.1 Correlation of anti-nutrient content and rate of damage

Table 5 presents the correlation matrix of various anti-nutrients, number of adult beetles and rate of damage observed. Flavonoid content was significantly and positively correlated with the rate of damage observed (r =0.464**; n=33). Phenol (r=-0.594**; n=33) and tannin (r=-0.660**; n=33) had significantly high negative relationship with the rate of damage recorded on chips. The alkaloid content of chips however, had no relationship (r= -0.006; n=33) with the damage rate.

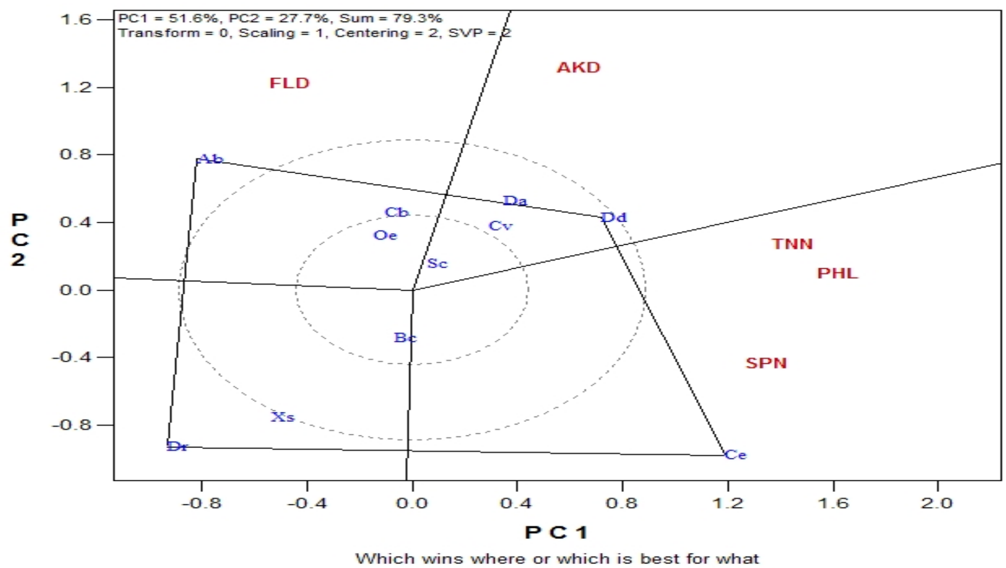

Fig. 3. Biplot analysis of chips types by antinutrient contents

FLD = Flavonoid, AKD = Alkaloid, TNN = Tannin, PHL = Phenol, SPN = Saponin, Ab = Agbagba, Cb = Cooking banana, Oe = Obino'l ewai, Da = Dioscorea alata, Dr = D. rotundata, Dd = D. dumentorum, Sc = Sweet cassava, Bc = bitter cassava, Ce = Colocasia esculenta, Cv = Colocasia esculenta var antiquorum, Xs = Xanthosoma sagittiffolium

Table 5. Linear correlation matrix of various anti-nutrients, number of adult beetles and the rate of damage observed in experiment three

Anti-nutrients	Tannin	Alkaloid	Flavonoid	Phenol	Saponin	Number of adult beetles	Rate of damage
Tannin	1.00	0.315	-0.13	0.814**	0.531**	-0.283	-0.660**
Alkaloid		1.00	0.307	0.409*	-0.016	-0.142	-0.006
Flavonoid			1.00	0.316	-0.277	0.321	0.464**
Phenol				1.00	0.733**	-0.105	-0.594**
Saponin					1.00	0.24	-0.214
Number of adult beetles						1.00	0.360*
Rate of damage							1.00

*NB **. = Correlation is significant at the 0.01 level (2-tailed)*

6.1.5.2 Mineral constituents of various chips

The various chips differed significantly from one another in their mineral contents (Table 6). The chips had higher contents of magnesium (Mg), calcium (Ca) and potassium (K) than iron (Fe), zinc (Zn), sodium (Na) and phosphorus (P) from. Of all the chips analysed, *C. esculenta* recorded the highest Ca content (19.00mg/100g) followed by *D. dumentorum* (15.00mg/100g). *Obinol* and sweet cassava chips (7.00 mg/100 g each) had the lowest. Results of the phosphorus analysis showed that among the various chips, cassava had the highest content followed by cocoyam chips and plantain had the least. Cocoyam chips recorded the highest iron compared to other chips. It was however followed by *Musa* chips and the least was cassava chips. Of all the chips analysed, *ugwuta* had the highest K (17.12 mg/100 g) followed by *C. esculenta* (16.95mg/100g) and the least was bitter cassava chips (2.00mg/100g). Zinc content differed significantly among chips. Cooking banana had the highest (6.36mg/100g) while *D. alata* had the least (1.27mg/100g).

Table 6. Mineral composition of various sun dried *Musa* and root/tuber chips (mg/100g)

Chips	Calcium	Magnesium	Phosphorus	Iron	Sodium	Potassium	Zinc
Agbagba	10.00*b*	25.20*i*	1.00*a*	3.06*c*	3.94*a*	8.48*e*	3.82*c*
Cooking banana	9.00*ab*	24.00*h*	1.35*b*	2.68*b*	8.84*d*	10.21*f*	6.36*e*
Obino'l Ewai	7.00*a*	22.80*g*	1.00*a*	3.45*d*	8.75*d*	7.09*c*	5.09*d*
Sweet cassava	7.00*a*	11.43*c*	8.75*f*	2.68*b*	4.92*b*	5.84*b*	5.10*d*
Bitter cassava	12.00*c*	12.60*d*	8.75*f*	1.91*a*	4.91*b*	2.00*a*	2.54*b*
C. esculenta	19.00*f*	30.00*j*	4.00*e*	4.21*f*	13.75*e*	16.95*i*	3.85*c*
X. sagittifollium	10.00*b*	10.20*a*	2.15*c*	3.06*c*	4.91*b*	10.72*g*	2.54*b*
C. esculenta var antiqorum (Ugwuta)	14.00*d*	24.00*h*	2.15*c*	3.84*e*	8.84*d*	17.12*j*	3.82*c*
Dioscorea alata	8.00*a*	11.40*b*	2.75*d*	3.06*c*	8.84*d*	11.85*h*	1.27*a*
D. dumentorum	15.00*de*	14.40*e*	2.65*d*	3.06*c*	5.82*c*	7.20*c*	3.80*c*
D. rotundata	13.00*cd*	20.40*f*	2.00*c*	2.67*b*	5.89*c*	7.77*d*	5.09*d*

Means followed by the same letter in the same column do not differ significantly according to Duncan's New Multiple Range Tests ($p<0.05$).

6.1.5.3 Biplot of chips types by mineral composition

The chips by mineral contents biplot analysis explained 70.50% (51.20 %+19 30 %) of the total variation in the mineral content of chips as a result of differences in chips types (Fig. 4). *Dioscorea alata* (Da), *C. esculenta* (Ce), cooking banana (Cb), bitter cassava (Bc) and sweet cassava (Sc) are the most highly divergent in their mineral contents as they appeared at the vertex of the pentagon formed and therefore constituted the vertex chips. Bitter cassava was mostly influenced by its phosphorus content while *C. esculenta* (Ce) and *C. esculenta* var *antiquorum* (Cv) were mostly influenced by calcium, potassium, sodium, iron and magnesium contents. Cooking banana, *Obino'l*, *Agbagba* and *D. rotundata* were mostly influenced by their zinc contents.

6.1.6 Correlation analysis

The correlation matrix of the various minerals analysed as shown in table 7 revealed that calcium (r=-0.450**; n=33) and iron (r= - 0.591**; n=33) had significant negative relationship with the rate of damage observed among chips. On the other hand, sodium (r =0.470**; n=33) and zinc (r=0.353*; n=33) had significant positive relationship with the rate of damage observed.

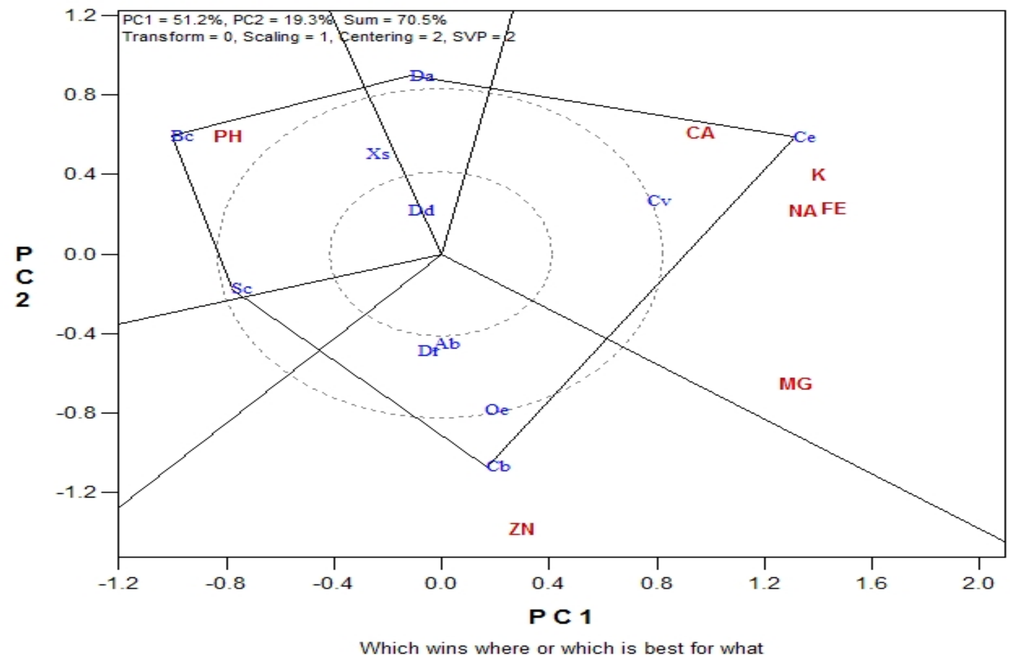

Fig. 4. Biplot analysis of chips types by mineral contents

PH = Phosphorus, CA = calcium, K = Potassium, NA = Sodium, FE = Iron, MG = Magnesium, ZN = Zinc, Bc = Bitter cassava, Sc = Sweet cassava, Dr = Dioscorea rotundata, Da = D. alata, Dd = Dioscorea dumentorum, Ab = Agbagba, Cb = Cooking banana, Oe = Obino'l ewai, Ce = Colocasia esculenta, Cv = Colocasia esculenta var antiquorum, Xs = Xanthosoma sagittiffolium

Table 7. Linear correlation matrix of various mineral, number of adult beetles and rate of damage observed in experiment three

	Ca	Mg	P	Fe	Na	K	Zn	No of adult beetles	Rate of damage
Ca	1.00	0.424*	-0.009	0.433*	0.427*	0.519**	-0.097	0.205	-0.450**
Mg		1.00	-0.468**	0.599**	0.591**	0.192	0.490**	0.869**	0.045
P			1.00	-0.460**	-0.211	0.264	-0.162	-0.343	0.260
Fe				1.00	0.713**	0.168	0.006	0.342	-0.591**
Na					1.00	0.423**	0.082	0.369*	0.470**
K						1.00	-0.443**	0.156	-0.107
Zn							1.00	0.553**	0.353*
Number of adult beetles								1.00	0.362*
Rate of damage									1.00

*NB **. = Correlation is significant at the 0.01% level (2-tailed).*

7. DISCUSSION

All the chips reacted differently to attack by beetles due to variation in their biochemical contents and how the various contents influence them. According to previous research, the rate of damage on chips by pests depends on a number of factors which include; texture of the chips (softness or hardness of the chips) [14], partial gelatinization of starch as a result of parboiling, which causes hardening of chips [26], biochemical contents of the chips (nutrients and anti-nutrients), which could encourage or discourage pests survival and multiplication [27], in addition to environmental conditions (temperature, humidity etc.) [28] and the type of pests. This result revealed that *C. esculenta*, *D. alata* and *D. dumentorum* chips discouraged the survival and activities of *T. castaneum*. Thus, low survival rate of beetles was observed in these chips in addition to low rate of multiplication and destruction of chips.

The biplot analysis and correlation results showed that Ce was highly influenced by its calcium, iron, phenol, saponin and tannin contents. The correlation matrix also revealed that these minerals and anti-nutrients except saponin had highly significant relationship with the rate of damage observed. They, however may have conferred resistance to the chips. This finding agrees with the report of Potenza et al. [19], who stated that right combinations of anti-nutrients could possess protective functions against pests. *Musa* spp. on the other hand, were influenced by their flavonoid and zinc contents which showed significant positive relationship with the rate of damage observed. Flavonoid and zinc also may have contributed to the rate of damage recorded among *Musa* chips and so the susceptibility of these chips to attack by the beetles. CV chips were highly influenced by calcium, iron, potassium, sodium and magnesium with almost no influence of the anti-nutrients. Among these minerals calcium and iron have significant negative relationship with the rate of damage observed in the chips. Iron and calcium however had contributed to the resistance of the cv chips to attack. *D. alata* chips exhibited resistance which can be as a result of other factors as buttressed by the biplot analysis and correlation results. Cassava lost the highest weight especially bitter cassava followed by the *Musa* spp. This corroborates the high vulnerabilities of these products to flour beetle as observed by Isa et al, [2], which states that cassava chips are not only soft but have been reported as a suitable substrate for *T. castaneum*. These findings also confirm the work of Ziegler [29] that oviposition rate and emergence of new adults depend greatly on the quality and type of substrate available to the organism. The susceptibility of *Musa* and cassava chips to attack by the beetles was therefore attributed to the nutritional contents of these chips and their ability to support the development of the insects. Campbell and Runnion [14] noted that a slight difference in quality of feed substrate can affect *Tribolium* spp. development considerably, The softness of the dried chips may have facilitated easy tunnelling of these chips by beetles and their ability to oviposit on the dried chips, feed and produce high quantity of frass. All these reports points to the fact that the development of *T. castaneum* in any substrate is highly dependent on the content (biochemical) of the medium. This result agrees with the reports of Okunade [30] and Jayasingle and Fujimoto [31] that allelochemicals including alkaloid, flavonoid, phenol, saponin etc. affect insect endocrines development as juvenile hormones, resulting in sterile adults. Thus, even when the pests are there, their activities and reproduction may be greatly discouraged is largely affected [30].

Some of these allelochemicals have been reported to play protective roles in plants [32], thereby discouraging attack of such plants or plant parts by pests [19]. Various research reports showed that the biochemical content of plants exert their effects in various ways on the target pests including, insecticidal, repellent, development inhibition and ovicidal

[33,34,35]. In *D. dumentorum and D. alata* chips prolonged development time and slow rate of multiplication of beetles, which invariably lead to low rate of damage and low percentage loss could be as a result of other factors since there was very insignificant relationship between the rate of damage observed in these chips and their anti-nutrient and mineral content. Factors like hardiness due to gelatinization of starch content of chips as a result of parboiling or other contents that were not analysed by this work may have contributed to discourage pests attack.

In *C. esculenta* var *antiqorum* the level of damage observed could be attributed to the high influence of mineral e.g. Ca, Mg, K, Fe and Na. Among these minerals Ca and Fe had significant negative correlation with the rate of damage observed which implied that higher content of these minerals in the chips will further reduce the rate of damage of the chips by beetles.

Usually, when environmental conditions are not favorable, developmental time of storage pests become prolonged. Under unfavourable conditions the maturation time of the pests slows down. It can therefore follow that increasing some of these anti-nutrients in the plants or plant parts can make the substrate environment unfavorable to these pests. However, These biochemicals are safe for man and animals that will consume the products.

8. CONCLUSION AND RECOMMENDATION

Results obtained from this study confirmed that various crop chips can be attacked by *T. castaneum*, which was found to exert different degrees of attack on *Musa* spp and root/tuber chips. Variation in the proximate, anti-nutrient and mineral contents of these chips resulted in their differential susceptibilities or resistances to *T. castaneum* attack. This knowledge can be of great importance to breeders who may utilize this to develop more resistant varieties of crops by increasing those biochemical contents that may confer resistance to these crops and thereby bridge the gap in knowledge concerning the control of this pest. More collaborative research should however be encouraged among crop protectionists, physiologists and plant breeders.

Table 3. Proximate composition of various sun dried plantain and root/tuber chips (%)

Chips	Carbohydrates	Protein	Fibre	Dry matter	Ash	Fat
Agbagba	79.49*d*	3.50*e*	0.70*a*	86.00*a*	2.00*b*	Trace
Cooking banana	81.42*d*	2.98*c*	1.60*c*	88.00*c*	2.00*b*	Trace
Obino'l Ewai	80.89*d*	3.41*d*	1.20*b*	87.00*b*	1.50*a*	Trace
Sweet cassava	81.82*d*	2.28*b*	0.40*a*	86.50*a*	2.50*c*	Trace
Bitter cassava	82.25*de*	1.84*a*	0.40*a*	86.00*a*	1.50*a*	Trace
C. esculenta	69.36*a*	9.54*h*	0.60*a*	86.50*a*	7.00*f*	Trace
X. sagittifollium	81.16*d*	3.94*f*	1.40*bc*	87.00*b*	3.50*d*	Trace
C. esculenta var antiqorum (Ugwuta)	76.93*bc*	5.17*h*	0.40*a*	87.50*b*	5.00*e*	Trace
Dioscorea alata	76.33*bc*	6.57*i*	0.60*a*	87.50*b*	4.00*d*	Trace
D. dumentorum	74.44*b*	8.06*j*	2.00*d*	87.00*b*	2.50*c*	Trace
D. rotundata	77.61*c*	5.08*g*	0.80*b*	86.00*a*	2.50*c*	Trace

Means followed by the same letter in the same column do not differ significantly according to Duncan's New Multiple Range Tests (p < 0.05).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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