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Productivity of *Tribolium* Species (Coleoptera; Tenebrionidae) within
Flours Derived from Edible Tubers and Effects on Proximate
Composition

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ABSTRACT

The productivity of *Tribolium* species within flours derived from edible tubers and effects on proximate composition were assessed. Population of adults *T. castaneum* were obtained from infested product of flour commodities by grain merchants at Samaru Zaria Market. The experiment was carried out in the Laboratory in a Completely Randomized Design (CRD) with triplicates. Four edible tubers yam (*Dioscorea* sp.), cassava (*Manihot esculenta*), sweet potatoes (*Ipomoea batata*), and cocoyam (*Colocasia esculenta*) were flake and sun dried and then pulverised to powdered form, 8g of each were then measured. Proximate analysis was conducted. The level of moisture in the flours ranges from 7.10% - 12.50%, ash (0.16% - 1.27%), lipid (0.10% - 0.58%), crude protein (2.50% - 12.00%), crude fiber (0.10% - 1.10%), carbohydrate (86.05% - 96.52%). It was concluded that low amounts of ash, lipid, moisture and proteins in cocoyam flour compared to other flours can explain why *T. castaneum* was not able to develop and multiply faster on this flour. Cocoyam flour showed the lowest level of total weight loss, thus it is considered as the least susceptible to infestation, while sweet potatoes and yam had the highest level of total weight loss, thus they were the most susceptible. It was therefore recommended that when considering *T. castaneum* management on stored flours, more attention and concentration should be directed towards comparing of cereals flours with root and tubers flours in order to determine which flour has the highest vulnerability to infestation.

Keywords: adult; edible; grains; population; infested;

1.0 INTRODUCTION

Insects are the major pests of cereals grain or flour during storage. Damage due to insects affects the quality, the quantity, the commercial and agronomic value of the products. Many pests of stored products are Coleopterans and the most destructive tropical species belong to the genus *Sitophilus* and *Tribolium* (Doumbia *et al.*, 2014). Insects belonging to the order Coleoptera, family Tenebrionidae and genus *Tribolium* have representatives that are cosmopolitan pest associated with stored product (Adebote *et al.*, 2008). The genus *Tribolium*, a member of these taxa is particularly notorious in floury foodstuffs acting as commensals with human and causing loss in nutritive value and alteration of the

biochemical composition of food materials, two species of coleopterans that are associated with floury product are the *T. Confusum* and *T. castaneum* (Adebote *et al.*, 2008). Damaged due to pest of the genus *Tribolium* flours or other cereal processed products, are mostly impurities and stains which would be capable of poisoning consumers (Tamgno and Tinkeu, 2014). The excrements and other exudations from the larvae of this pest contaminate the food which tends to smell and thus lose their commercial or nutritional value (Tamgno and Tinkeu, 2014). This bad smell is accentuated by the nauseous pheromones produced by the adult beetles (Tamgno and Tinkeu, 2014). The control of pests in stored products, by the application of chemicals

which is a common strategy for post-harvest loss avoidance, had led to the occurrence of many problems like the pollution of environment, toxicity to humanbeing, emergence of resistant pests strains and many others damages (Oerke, 2006). These synthetic pesticides are expensive for the small scale farmers and pose potential risks due to the lack of technical knowledge on their safe use. Due to the undesirable effects of chemical insecticides on the environment, human health and useful organisms, recent researches have been undertaken in order to minimize the agro-environmental pollution and health hazards caused by them and to replace them with other methods. Hence, there is need to explore new effective biological pests control methods which can confer protection to crops against insect pests (Bale *et al.*, 2007). The most efficient crop protection method nowadays must be one which employs a consumer and environmentally friendly approach. Among the recent methods, biological methods are one of those which offer ecological solutions that respect the environment (Popp *et al.*, 2013). The bacterial proteins which are widely used and sold as biological insecticides since 1950 were the first effort for this purpose (Sanchis, 2011). Other supplemental methods, including the use of entomotoxic proteins were introduced in crop protection; due to resistance of some insect pests to repeated toxin applications and none affected Homopterans pests by toxins (Siegwart *et al.*, 2015). The use of protecting materials which are edible by human and other animals may be a good alternative in pest control. In this context, the development of a new approach for the protection of stored food stuff based on the use of the natural and edible food substances such as leguminous plants containing entomotoxic proteins would reduce considerably the environmental risks associated with the use of these phytosanitary materials for protection (Tripathi, 2018). Leguminous plants have many entomotoxic proteins like lectins which have the insecticidal activity towards many insect taxa such as Coleoptera, Lepidoptera and Homoptera (Tripathi, 2018).

The rust-red flour beetle, *Tribolium castaneum* (Herbst), is one of the most widespread and destructive pests of stored products, feeding on different stored grain and grain products in the hot

humid tropical regions of the world (Kayode *et al.*, 2014). In Nigeria, the host range of the rust red flour beetle includes a wide range of food stuffs such as milled cereal products like wheat, sorghum, millet, acha, benniseeds, oil seed cake, cowpea, groundnuts, dried roots and tubers of yam, cassava, cocoyam, plantain among others (Kayode *et al.*, 2014). The red four beetle *Tribolium castaneum* (Herbst) is a pest that infests stored products such as flour and other milled cereal products or broken grains (Jeyasankar *et al.*, 2016) in food processing facilities (Raj Boina *et al.*, 2008) and flour mills, warehouses, and retail stores (Toews *et al.*, 2009). This species can colonize small patches of food and sustain itself with small amounts of food (Ahmad *et al.*, 2013). It has often been used as a model for ecological studies because of its ability to colonize a wide range of stored products (Malekpour *et al.*, 2018). *T. castaneum* can readily fly when the environment is warm (Hernandez Nopsa *et al.*, 2015), and it is capable of dispersal in various foods, including grains and flour stored in a storage area (Edde *et al.*, 2012).

Adult females *Tribolium* sp. have a long life span and can lay eggs in a relatively continuous manner throughout their life (Fabres *et al.*, 2014) and had been reported to lay up to 1,000 eggs during their lifetime (Wong and Lee, 2011). The oviposition rate and emergence of new adults depend greatly on the quality and type of the substrate available (Chukwulobe and Echezona, 2014). In previous studies, preferences for stored food products were evaluated in an attempt to identify diets that are suitable for their growth and development (Stejskal *et al.*, 2015). Ajayi *et al.* (2019) noted that different types of flour contain different nutrients and a slight difference in quality can affect *Tribolium* sp. development considerably. Fardisi *et al.* (2016) showed that the growth of *T. castaneum* was slow when the insects were reared in wheat, brown rice, and rice, but the addition of yeast improved their development. Their study emphasized on the addition of yeast at a ratio of 19:1 (four: yeast) into the diets but did not examine the level of protein that was suitable for the growth of the *Tribolium* beetles. Other studies had evaluated the dietary requirements of stored product insects such as *Tribolium confusum*, with emphasis on sterols, carbohydrates, amino acids,

vitamins and minerals (Morales-Ramos *et al.*, 2014). According to Đukić *et al.* (2016), most of the previous studies focused on the effects of various components of a diet on developmental rate and mortality of the larvae number of larval instars, or weight of larvae, pupae, or adults. Various minerals and vitamins for the optimal growth of *T. confusum* have been investigated and this includes phosphorus (Wong and Lee, 2011), thiamine, ribofavin, nicotinic acid, pyridoxine, pantothenic acid, and biotin (Wolf, 2006). Nevertheless, studies on the influence of a definite range of nutrients, especially protein and carbohydrates for the optimal growth and development of *T. castaneum* were never attempted.

In granaries or flour mills, *Tribolium* sp. usually is exposed to only one or two grain types. However, mills may also produce and store several types of grain at the same time, thereby providing the opportunity for selection in a spatially heterogeneous environment (Wong and Lee, 2011). These beetles can disperse over different flour types kept in particular storage areas where the environmental conditions (temperature and humidity) are kept at a constant, but they may or may not thrive. The aim of this study is to produce *Tribolium* species (Coleoptera; Tenebrionidae) within flours derived from edible tubers and effects on proximate composition. The objectives are to determine the nutritional value of flour of edible tubers boiled and sundried and unboiled and sundried before and after infestation by *T. Castaneum*, to determine Larvae and Pupae Occurrence as well as Productivity of *Tribolium castaneum* in the Flours and to determine Mean Weight Loss in Flours due to Feeding by *Tribolium castaneum*

2.0 MATERIALS AND METHODS

2.1 Study Area

The research was carried out at the Entomology Laboratory, Department of Zoology, Ahmadu Bello University, Zaria (Latitude: 11° 9' 2.16"N and Longitude: 7° 39' 17.28"E).

2.2 Sample Collection

Population of adults *T. castaneum* were obtained from infested product of flour commodities by grain merchants at Samaru Market (Latitude: 11°

9' 55.3"N and Longitude: 7° 39' 5.84"E), Zaria, Nigeria.

2.3 Experimental Design

The experiment was carried out in the Laboratory in a Completely Randomized Design (CRD) in triplicates.

2.4 Sample Preparation

2.4.1 Insect Culture

The beetles were sorted out microscopically using the identification keys of Haines (1991).

2.4.2 Processing the Edible Tubers into Flour

The tubers were processed in two ways, the first one was unboiled and sundry and then the second was parboiled and sundry. The four edible tubers yam (*Dioscorea* sp.), cassava (*Manihot esculenta*), sweet potatoes (*Ipomoea batata*), and cocoyam (*Colocasia esculenta*) were flake and sun dried and then pulverised to powdered form, 8g of each were then measured.

2.5 Determination of Nutritional Value of Flour Samples

Proximate analysis was conducted following the standard procedures of the Association of Official Analytical Chemists (AOAC, 2005) to ascertain the nutritional composition (ash, lipid, fiber, protein and carbohydrate) present in each diet type. Before the analyses, the flour samples were stored in desiccators. Each flour sample was analyzed before and after introduction of the insects.

2.5.1 Ash Content

Ash content was determined by placing 2g of flour or starch in a crucible and then ash drying it in a muffle furnace at 600 °C for 5 hrs. The weight of each flour sample was measured before and after the assay and the ash content was calculated as the difference between the two measurements (AOAC, 2005).

2.5.2 Lipid Content

Lipid content was estimated by homogenizing 1g of the flour in a mixture of analytical grade methanol and chloroform at a ratio of 2:1 and then separating the solution using a separating funnel. The lower phase (solvent and lipid extract) was collected in a beaker and left in an oven at 105 °C

for 3 hrs to evaporate the solvents before weighing the sample (AOAC, 2005).

2.5.3 Crude Fiber Content

Crude fiber content was estimated by heating 2 g of the four or starch sample in H_2SO_4 (5% vol : vol) and water, then adding NaOH (40% vol : vol) and a few drops of indicator before heating again. The solution then was rinsed with 1% HCl and boiling water through a Buchner funnel equipped with a filter paper (Whatman no. 541). The filter paper was placed in a crucible and left in the muffle furnace at 600 °C for 3 hrs before weighing.

2.5.4 Crude Protein

Each flour sample prepared to determine crude fiber was also subjected to digestion and analysis using the standard Kjeldahl method to assess the crude protein content.

2.5.5 Crude Carbohydrate Content

Crude carbohydrate content was estimated by subtracting the total sum of percent crude protein, crude lipid, crude fiber and ash from 100%.

$$\text{Crude Carbohydrate} = 100\% - (\% \text{ Crude protein} + \% \text{ Crude lipid} + \% \text{ Crude fiber} + \% \text{ Ash})$$

2.5.6 Moisture Content

Small sample of flour (2–3 grams) were weighed, grinded and placed into a dish. The sample was heated at 130°C in an oven for 60 minutes. The sample was cooled to room temperature and the residue (dried sample) was weighed. Moisture content was determined by comparing the weight of the sample before and after heating. The moisture content is calculated by the following formula:

$$\% \text{ Moisture} = \frac{\text{Loss in moisture (g)}}{\text{Initial weight of sample (g)}}$$

Where: Loss in moisture = Initial weight (g) – Final weight (g)

Initial weight = Wet or original weight of sample before drying

Final weight = Weight of sample after drying

2.6 Determination of Larvae and Pupae Occurrence as well as Productivity of *T. castaneum* in the Flours

After sorting, ten pairs of the virgin of *T. castaneum* were introduced into 8g of each of the 8 flour media each species in triplicates and were allowed to reproduce for a period of one month. The larval and pupal occurrence as well as productivity of *T. castaneum* in each medium were determined by counting their population as described by Adebote *et al.* (2008).

2.7 Weight Loss in Flours of Sweet potato, Cassava, Cocoyam and Yam due to Feeding by *T. castaneum*

The loss in weight due to infestation by *T. castaneum* was determined in the four types of tuber and root flours. The net weight loss due to insect feeding at storage periods of one month was obtained by subtracting the flour weight in the infested from the initial weight.

2.8 Data Analyses

The Nutritional values of Flour samples obtained before and after introduction of the Insects, Larvae and Pupae Occurrence, Productivity of *T. castaneum* and Mean Weight Loss in Flour samples due to feeding by *T. castaneum* were analyzed using a one-way analysis of variance (ANOVA) at 5% level of significance.

Duncan's Multiple Range Test (DMRT) was used to separate the means where significant differences were observed. T-test was used to determine the relationship between proximate compositions of the Flours and the Developmental Stages (Larva, Pupa and Adult) of *T. castaneum*. All analyses were performed using SAS V. 9.2 (2008).

3.0 RESULTS AND DISCUSSION

3.1 Proximate Composition of Flours Before and after Infestation by *Tribolium castaneum*

The proximate compositions of flours before and after infestation by *Tribolium castaneum* were presented in table 4.1 and 4.2. The nutritive value of a food source is largely dependent on its proximate compositions and foods deficient in proteins, for instance, are expected to be of inferior quality. Insects develop and multiply rapidly when they are fed on high quality food.

Hence when *T. castaneum* is fed on different types of flours, it is expected that its performance will differ according to the food quality of each flour type. In our effort to explain why some types of flours are more suitable in enhancing development and multiplication of *T. castaneum*, we carried out an analysis of the proximate composition of these flours (Tables 1 and 2). Generally, the level of moisture content in the flours ranges from 7.10% - 12.50%. Ash contents in the flours ranges from 0.16% - 1.27%. The lipid content of the flours was found to be in the range of 0.10% - 0.58%. However, crude protein contents of the flours were in the range of 2.50% - 12.00%. Crude fiber was in the range of 0.10% - 1.10%. Carbohydrate levels were found to be in the range of 86.05% - 96.52%. The highest values of moisture (12.50%), ash (1.27%), lipid (0.58%) and protein (12.00%) were recorded in sweet potatoes (boiled and sundried), while the least values were recorded in cocoyam. Similarly, the highest values of crude fiber (1.10%) and carbohydrate (96.52%) were recorded in cocoyam while the least were recorded in sweet potatoes.

The results of proximate composition of flours before and after infestation showed lower amounts of ash, lipid, moisture and proteins in cassava and cocoyam, this may explain to some extent why *T. castaneum* was not able to develop and multiply faster on cassava and cocoyam flours because these ingredients are essential for growth. The finding that the cocoyam flour had the highest carbohydrate content and crude fiber, followed by cassava flour, while sweet potatoes and yam have the lowest amounts, can indicate that carbohydrates are important energy source, however their contribution to body building and total growth is rather limited. This is in line with the findings of Sharma (2013) who investigated the relative resistance of wheat varieties to the attack of *Trogoderma granarium* and concluded that varietal susceptibility was associated with the softness of the germ portion of the grain and possibly with its high carbohydrate content. Sharma (2013) concluded that none of the wheat varieties tested in the laboratory in India, were immune to *T. castaneum*, but that high protein content and adequate moisture levels were probably linked to susceptibility. Bhatia and Sethi (1989) attributed the low infestation of *T.*

castaneum on flours and seeds of four varieties of Bengal gram *Cicer arietinum* to the low protein and amino acid contents and texture of the food substrate. The high infestation of wheat flour was due to the high protein and amino acid contents of the seeds.

3.2 Larvae and Pupae Abundance as well as Productivity of *T. castaneum* in the Flours

The abundance of larval and pupal stages of *T. castaneum* as well as the productivity of *T. castaneum* in the four flour media following one month of incubation is presented on Table 4.3.

The highest mean number of larvae (22) was isolated from Sweet potatoes flour, while cassava flour produced the least number of larvae (17) to nil in cocoyam and nil (0) in cocoyam. The abundance of *T. castaneum* larvae differs significantly amongst the flour media ($p \geq 0.05$). Pupal *T. castaneum* abundance in the flours ranged from 15 observed in Sweet potatoes and yam followed closely by 13 obtained in Yam, to nil in Cocoyam. Observed differences in pupal abundance were statistically significance ($p \geq 0.05$). The trend of larvae and pupae *T. castaneum* abundance in the media was Sweet potatoes > Yam > Cassava > Cocoyam.

Productivity of *T. castaneum* has been determined in the following tubers: sweet potatoes per boiled and sundried, sweet potatoes unboiled and sundried, yam per boiled and sundried, yam unboiled and sundried, cassava per boiled and sundried, cassava unboiled and sundried, cocoyam per boiled and sundried, cocoyam unboiled and sundried (Table 4.3). Significant differences in productivity have been detected in the different media within 1 month. Cocoyam both boiled and unboiled medium is unfavorable for the species (0.00). *T. castaneum* performs poor in cassava media (4-7), better in yam media (10-11) and the best in sweet potatoes (9-13). These occur in boiled and unboiled but in boiled is higher than unboiled in all the flours. The species shows rapid increased productivity in sweet potatoes boiled and unboiled within 1 month. The trend of adult *T. castaneum* abundance in the media was Sweet potatoes > Yam > Cassava > Cocoyam.

Tribolium castaneum larvae and pupae produced fastest in sweet potatoes flour compared to the other three (3) studied. This was because sweet potatoes flour supported the development by far the highest population of *Tribolium castaneum* larvae and pupae as a result of high amount of protein, ash, lipid and moisture. Absence of larvae and pupae in cocoyam flour indicates least amount of these nutrients in the flour. Khalifa and Badawy (1995b) showed that different types and forms of food on which *T. castaneum* was reared affected the speed of larval development. The differences in the productivity of larval and pupal *Tribolium castaneum* in these flour media indicate the polyphagous nature of the insect. This is in line with the findings of Cambell and Runnions (2003) that have earlier emphasized the polyphagous nature of *Tribolium castaneum* especially in the flour meals.

The differences in the larval and pupal abundance of *Tribolium castaneum* in the four flour media investigated in this study could be due to combination of physical and chemical characteristics of the media. These factors could have affected the viability of eggs, larvae and pupae stages produced by the insects in the different substrates.

The results obtained in this study demonstrate the differences in the productivity of *Tribolium castaneum* in various flour media derived from roots and tubers that demonstrate part of the staple diet of many Nigerians. These roots and tubers are often processed into flour, stored and or utilized as such in the preparation of human meals.

The productivity depends on the high amount of moisture content, ash, lipid and crude protein with low carbohydrate and crude fiber contents which occurs highest in sweet potatoes. This is in agreement with the findings of Balagopalan (2018) who stated that practically any kind of flour might be infested, especially whole wheat flour which seemed more liable to attack with high proximate compositions and low carbohydrate content.

3.3 Mean Weight Loss in Flours due to Feeding by *Tribolium castaneum*

The losses in weight (g) of flours of sweet potatoes, cassava, cocoyam and yam caused by the

feeding of *T. castaneum* over a period of one month are presented (Table 4.4). Analysis of variance for weight loss of the four types of flour was presented. Differences in weight losses were recorded among the four flours infested by *T. castaneum* at a period of one month storage. The samples of flours of sweet potatoes and yam suffered more losses in weight (0.27g and 0.21g respectively), than cassava and cocoyam (0.15g and 0.00g, respectively) (Table 4.4). Increase in weight loss was observed boiled and sundried storage in all infested flours, particularly in sweet potatoes and yam flours.

The mean weight loss that occurred in sweet potatoes, yam and cocoyam could be attributed to their high proximate compositions as oppose to cocoyam with highest carbohydrate contents that tends to limit growth of the insects. This is in line with the findings of Burkset *al.* (2015) who concluded that *T. castaneum* was well known as pest of flour and other milled cereal products and was commonly regarded as a secondary pest of stored wheat and flours. Paulet *al.* (2020) also reported that red flour beetles primarily attacked milled grain products, such as flour and cereals. The present results confirmed the ability of *T. castaneum* to survive and develop well in the three flours (sweet potatoes, yam and cassava). Thus in stores where *T. castaneum* is really a serious problem, a practice may be developed to sieve the flours through suitable sieves before storage. This will at least partly reduce the initial infestation by this pest.

3.4 Relationship Between Proximate Compositions of the Flours and the Developmental Stages (Larva, Pupa and Adult) of *T. castaneum*

Relationship between Proximate Compositions of the Flours and the Developmental Stages (Larva, Pupa and Adult) of *T. castaneum* (Table 4.5). Pearson's correlation analysis allowed noticing that, some parameters were strongly positively or negatively correlated between them. A strong positive correlation ($p < 0.05$) was found between moisture and ash ($r = 0.914^{**}$), moisture and lipid ($r = 0.920^{**}$), moisture and crude protein ($r = 0.898^{**}$), ash and lipid ($r = 0.876^{**}$), ash and carbohydrate ($r = 0.852^{**}$), lipid and carbohydrate ($r = 0.942^{**}$), crude fiber and carbohydrate ($r = 0.876^{**}$), crude fiber and lipid ($r = 0.852^{**}$), crude protein and carbohydrate ($r = 0.898^{**}$), crude protein and lipid ($r = 0.876^{**}$), and carbohydrate and lipid ($r = 0.852^{**}$).

0.841**), crude protein and adult ($r= 0.853**$), larva and pupa ($r= 0.942**$), larva and adult ($r= 0.952**$) and pupa and adult ($r= 0.917**$). A positive correlation ($p < 0.05$) between moisture and larva ($r= 0.726^*$), moisture and adult ($r= 0.798^*$), ash and crude protein ($r= 0.795^*$), lipid and larva ($r= 0.744^*$), lipid and adult ($r= 0.758^*$), crude protein and larva ($r= 0.817^*$) and crude protein and pupa ($r= 0.769^*$). A strong negative correlation ($p < 0.05$) was found between moisture and carbohydrate ($r= -0.930**$), lipid and carbohydrate ($r= -0.954**$), crude fiber and crude protein ($r= -0.876**$), crude fiber and larva ($r= -0.924**$), crude fiber and pupa ($r= -0.905**$), crude fiber and adult ($r= -0.891**$) and crude protein and carbohydrate ($r= -0.993**$). A negative correlation ($p < 0.05$) between moisture and crude fiber ($r= -0.722^*$), lipid and crude fiber ($r= -0.813^*$), carbohydrate and larva ($r= -0.789^*$), carbohydrate and pupa ($r= -0.733^*$) and carbohydrate and adult ($r= -0.823^*$).

The positive correlation (negative and strongly negative) between moisture, lipid, crude protein with the productivity of *T. castaneum* (larva, pupa and adult) could be as a result of higher contents of these nutrients enhances the productivity of *T. castaneum*. The positive correlations between moisture with ash, lipid and crude protein. Ash with crude protein and lipid. Lipid with crude protein. Crude fiber with carbohydrate and larva with pupa and adult as well as pupa with adult could be due to increase in one substrate results to increase in another substrate with enhances productivity as well as abundance of developmental stages of *T. castaneum*. These findings also confirm the work of Tait *et al.* (2020) that oviposition rate and emergence of new adults depend greatly on the quality and type of substrate available to the organism. The negative correlation (negative and strongly negative) between carbohydrates, crude fiber with the larva, pupa and adult observed could be attributed to the high influence of these nutrients on the reduction rate of developmental stages of *T. castaneum*. This implied that higher content of these nutrients in the flours will further reduce the rate of developmental stages of the beetles. Negative correlation between moisture, lipid, crude protein with carbohydrate and crude fiber could be

attributed to the higher proximate contents (moisture, lipid, crude protein) with lower carbohydrate and crude fiber enhances the productivity of developmental stages of *T. castaneum*. This is in line with the findings of Chukwulobe and Echezona (2014) who worked on Relative susceptibility of dried root/tuber and Musa chips to red flour beetle (*T. castaneum*) infestation and discovered that 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. Campbell and Runnion (2003) noted that a slight difference in quality of feed substrate can affect *Tribolium* spp. development considerably.

Table 1: Proximate Composition of Flours before Infestation by *Tribolium castaneum*

Flours	Moisture (%)	Ash (%)	Lipid (%)	C. F (%)	C. P (%)	CHO (%)
Sweet potatoes bs	12.00±0.55 ^a	1.20±0.15 ^a	0.55±0.10 ^a	0.10±0.05 ^e	11.80±0.52 ^a	86.35±0.92 ^e
Sweet potatoes us	11.40±0.50 ^b	0.80±0.17 ^b	0.60±0.17 ^a	0.10±0.05 ^e	11.10±0.50 ^a	87.40±0.94 ^e
Cassava bs	8.50±0.44 ^d	0.30±0.14 ^d	0.18±0.12 ^d	0.50±0.10 ^c	3.10±0.20 ^d	95.92±0.95 ^b
Cassava us	7.30±0.41 ^e	0.24±0.14 ^d	0.19±0.12 ^d	0.40±0.10 ^c	5.50±0.36 ^c	93.67±0.97 ^c
Cocoyam bs	8.30±0.43 ^d	0.20±0.10 ^e	0.10±0.05 ^e	1.10±0.15 ^a	2.80±0.18 ^e	95.80±0.92 ^b
Cocoyam us	7.10±0.40 ^e	0.16±0.09 ^e	0.10±0.05 ^e	0.72±0.17 ^b	2.50±0.17 ^e	96.52±0.98 ^a
Yam bs	10.40±0.48 ^c	0.55±0.10 ^c	0.46±0.10 ^b	0.20±0.12 ^d	9.60±0.45 ^b	89.19±0.95 ^d
Yam us	10.00±0.45 ^c	0.45±0.10 ^c	0.32±0.14 ^c	0.20±0.12 ^d	9.90±0.45 ^b	89.13±0.96 ^d

KEY: C. F – Crude Fiber, C. P – Crude Protein, CHO – Carbohydrate, % - Percentage,

bs boiled and sundried, us – unboiled and sundried

Means with the same superscripts along the same column are not significantly different (p≥0.05).

Table 2: Proximate Composition of Flours after Infestation by *Tribolium castaneum*

Flours	Moisture (%)	Ash (%)	Lipid (%)	C. F (%)	C. P (%)	CHO (%)
Sweet potatoes bs	12.50±0.55 ^a	1.27±0.15 ^a	0.58±0.10 ^a	0.10±0.05 ^e	12.00±0.52 ^a	86.05±0.92 ^e
Sweet potatoes us	11.45±0.50 ^b	0.87±0.17 ^b	0.65±0.17 ^a	0.12±0.05 ^e	11.10±0.50 ^a	87.26±0.94 ^e
Cassava bs	8.56±0.44 ^d	0.32±0.14 ^d	0.20±0.12 ^d	0.50±0.10 ^c	3.14±0.20 ^d	95.84±0.95 ^b
Cassava us	7.33±0.41 ^e	0.25±0.14 ^d	0.19±0.12 ^d	0.40±0.10 ^c	5.55±0.36 ^c	93.61±0.97 ^c
Cocoyam bs	8.32±0.43 ^d	0.22±0.10 ^e	0.15±0.05 ^e	1.10±0.15 ^a	2.84±0.18 ^e	95.69±0.92 ^b
Cocoyam us	7.11±0.40 ^e	0.18±0.09 ^e	0.13±0.05 ^e	0.72±0.17 ^b	2.53±0.17 ^e	96.44±0.98 ^a
Yam bs	10.43±0.48 ^c	0.56±0.10 ^c	0.47±0.10 ^b	0.20±0.12 ^d	9.70±0.45 ^b	89.07±0.95 ^d
Yam us	10.20±0.45 ^c	0.48±0.10 ^c	0.35±0.14 ^c	0.20±0.12 ^d	9.94±0.45 ^b	89.03±0.96 ^d

Carbohydrate, % - Percentage, bs – boiled and sundried, us – unboiled and sundried

Means with the same superscripts along the same column are not significantly different (p≥0.05).

Table 3: Productivity of Ten Pairs of Adult *Tribolium castaneum* Beetles in Four Flour Media

Flour Media	Number (Mean ± SE) of Beetle Life Stages			Total
	Larva	Pupa	Adult	
Sweet potatoes boiled and Sundried	22(7.33±0.41) ^a	15(5.00±0.30) ^a	13(4.33±0.25) ^a	50
Sweet potatoes unboiled and Sundried	21(7.00±0.38) ^a	15(5.00±0.30) ^a	9(3.00±0.20) ^b	45
Cassava boiled and Sundried	17(5.67±0.39) ^c	13(4.33±0.25) ^b	7(2.33±0.18) ^c	37
Cassava unboiled and Sundried	16(5.33±0.32) ^c	13(4.33±0.25) ^b	4(1.33±0.15) ^d	33
Cocoyam boiled and Sundried	0.00±0.00 ^d	0.00±0.00 ^d	0.00±0.00 ^e	0
Cocoyam unboiled and Sundried	0.00±0.00 ^d	0.00±0.00 ^d	0.00±0.00 ^e	0
Yam boiled and Sundried	21(7.00±0.38) ^a	15(5.00±0.30) ^a	11(3.67±0.21) ^b	47
Yam unboiled and Sundry	19(6.33±0.40) ^b	14(4.67±0.28) ^c	10(3.33±0.20) ^b	43

Means with the same superscripts along the same column are not significantly different (p≥0.05).

Table 4: Mean Weight Loss in Flours due to Feeding by *Tribolium castaneum*

Flours	Weight Loss in Flours (g)
Sweet potatoes boiled and Sundried	0.15±0.11
Sweet potatoes unboiled and Sundried	0.09±0.10
Cassava boiled and Sundried	0.27±0.14
Cassava unboiled and Sundried	0.24±0.14
Cocoyam boiled and Sundried	0.00±0.00
Cocoyam unboiled and Sundried	0.00±0.00
Yam boiled and Sundried	0.21±0.12
Yam unboiled and Sundry	0.18±0.12

Means with the same superscripts along the same column are not significantly different (p≥0.05).

Table 5: Relationship between Proximate Compositions of the Flours and the Developmental Stages (Larva, Pupa and Adult) of *T. castaneum*

	Moisture	Ash	Lipid	CF	CP	CHO	Larva	Pupa	Adult
Moist	1.000								
Ash	0.914**	1.000							
Lipid	0.920**	0.873**	1.000						
CF	-0.722*	-0.690 ^{ns}	-0.813*	1.000					
CP	0.898**	0.795*	0.942**	-0.876**	1.000				
CHO	-0.930**	0.852**	-0.954**	0.841**	-0.993**	1.000			
Larva	0.726*	0.652 ^{ns}	0.744*	-0.924**	0.817*	-0.789*	1.000		
Pupa	0.655 ^{ns}	0.581 ^{ns}	0.685 ^{ns}	-0.905**	0.769*	-0.733*	0.995**	1.000	
Adult	0.798*	0.628 ^{ns}	0.758*	-0.891**	0.853**	-0.823*	0.942**	0.917**	1.000

KEY: * = Positive correlation (significant) at 0.05, **= Strongly Positive correlation (highly significant) at 0.05, -* = Negative correlation (significant) at 0.05, -**= Strongly Negative correlation (highly significant) at 0.05, ns= not significant, Moist – Moisture, CF – Crude Fiber, CP – Crude Protein, CHO - Carbohydrate

4.0 CONCLUSIONS

The following conclusions can be stated from the present study:-

1. The low amounts of ash, lipid, moisture and proteins in cocoyam flour compared to other flours can explain why *T. castaneum* was not able to develop and multiply faster on this flour. The findings show the importance of this pest, on flours of sweet potatoes, yam and cassava and that cocoyam flour appeared to be the least susceptible. Sweet potatoes and yam flours are the most vulnerable to infestation due to their high number of amounts of ash, lipid, moisture and proteins.
2. The sweet potatoes flours followed by yam flours with highest larvae and pupae abundance and lowest total productivity of *T. castaneum*, followed by yam flours, the highest levels indicate that these flours have highest vulnerability to *T. castaneum* infestation due to their high protein, ash, moisture and lipid contents.
3. Cocoyam flour showed the lowest level of total weight loss, thus it is considered as the least susceptible to infestation, while sweet potatoes and yam had the highest level of total weight loss, thus they were the most susceptible.

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