INFLUENCE OF FOUR CEREAL FLOURS ON THE GROWTH OF *TRIBOLIUM CASTANEUM* HERBST (COLEOPTERA: TENEBRIONIDAE)

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ABSTRACT

The influence of four cereals namely, flours of wheat (*Triticum aestivum* L.), millet (*Pennisetum glaucum* L.), sorghum (*Sorghum bicolor (*L.)Moench) and maize (*Zea mays* L.)on the growth and development of *T. castaneum* was investigated at ambient tropical laboratory conditions of 30±3°C and relative humidity of 75±5%. The anti-nutrients, mineral profile and proximate compositions of the four flour types and their effects on the developmental activity of the flour beetle were studied. Results showed that the moisture content of the cereal flours ranged from 7.64% in wheat to 9.24% in maize, while protein content ranged from 10.91% in millet to 17.23% in wheat flour and the ash content in the flours ranged from 1.05% in maize to 2.59% in millet. However, the four cereal flours had sufficient nutrients to support the growth of *T. castaneum*. Millet flour had the highest number of larvae (435.50±0.85) at 56-day post-infestation thus depicting millet flour as the most preferred flour type for oviposition and egg incubation; while the lowest (286.25±0.41) number of larvae was obtained in maize flour and it was significantly lower ($p \leq 0.05$) than the number of emerging larvae in other flour types. The highest number of pupae was recorded in millet (387.50±0.65) and lowest in maize flour (312.25±0.65). The highest number of emergent adult *Triboliumb* was recorded in millet (357.00±0.41) and lowest in maize (268.25±0.65). Host preference (choice and no-choice) studies revealed millet flour as the most preferred food and maize flour as the least preferred. Based on the flour colour, anti-nutrient composition and population of the immature forms of the flour beetle, maize flour was the most unsuitable food source, while millet flour was the most susceptible to *T. castaneum*.

Key words: Anti-Nutrients, Proximate Composition, Flour Colour, Cereal Flours, Rust-Red Flour Beetle, *Tribolium castaneum*.

INTRODUCTION

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 (Padin *et al*, 2013).

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 (Hill, 1983; Adedire & Oni, 1995; Lale & Yusuf, 2001; Odeyemi, 2001; Bulus, 2008).

T. castaneum does not possess the ability to infest and damage wholesome grains or products but they reproduce rapidly in milled or damaged grains and products. Their short life cycle coupled with low mortality of their immature forms account for the high reproductive success of this species (Howe, 1962). The larva is the most destructive stage of the beetle and its intensive feeding activity results in most serious damage to stored produce. The beetles contaminate the stored products with their excreta, exuviates, body odour and their cadavers thus reducing the palatability, rheological properties and market value of stored flours.

Recently, there is a huge decline in the use of synthetic insecticides in agriculture particularly in stored products protection in developing nations primarily because of partial or complete withdrawal of subsidies by governments, sustained propaganda on organic agriculture and undesirable health implications of the use of chemical pesticides and its effect on the environment by environmentalists and other concerned non-governmental organizations (Akinkurolere *et al*, 2011).

The application of resistant species and varieties has been the major focus of many researchers in recent times. According to Lale and Yusuf (2001), many research efforts appeared focused on high value crops such as maize, cowpea, rice, groundnuts etc. Food commodities are known to influence post-embryonic development in the Indian meal moth, *Plodiainter punctella* (Hubner). It is fairly well known that the life cycle of insects is greatly influenced by environmental factors notably the quality of food (Bouayad *et al.*, 2008). This has been demonstrated in storage beetles and moths (Savov, 1973; Locatelli & Limonta, 1998; Bulus, 2008).

Generally, four important mechanisms namely antibiosis, antixenosis, tolerance and escape are responsible for insect pest resistance. According to Keneni *et al.* (2011), escape and tolerance are resistance mechanisms that are only relevant to field crop infestations while antibiosis and antixenosis are applicable to storage insect pests. A number of physiological and/or biochemical mechanisms may protect stored crops from insect pest depredation. In legumes for example, an array of direct and indirect defenses such as morphological barriers, secondary metabolites and anti-nutrients confer resistance on legume seeds (Edwards &Singh, 2006).

Wheat, millet, sorghum and maize flours are highly consumed in many parts of sub Saharan Africa. They are a common staple food in developing countries including Nigeria. Their deterioration in storage due to the infestation by *T. castaneum* and other microorganisms leads to losses which in turn has adverse effects on the economy of the nation and health of the people. It is therefore necessary that such losses be investigated so as to provide adequate information that will guarantee food security in developing countries.

Hence, this study was conducted to determine the influence of four flours namely, wheat, millet, sorghum and maize on infestation and development of *T. castaneum* using proximate composition, mineral profile, anti-nutrients and beetle growth as indices.

MATERIALS AND METHODS

Source of Food Media and Insects

Four cereals namely wheat, sorghum, millet and maize grains, used for the experiments were purchased at the Akure main market ("Oja Oba" Akure), Ondo State and *T. castaneum* adult insects used were obtained from the Entomology Research Laboratory, Department of Biology, Federal University of Technology, Akure, Nigeria.

Preparation of the Food Media

The grains of maize, sorghum, wheat and millet used in this study were winnowed and thoroughly sorted to remove stones and other foreign materials. The seeds were then pulverized into fine powder in a "Muchang blender model No. 9FZ-300" until finely divided powder was obtained. The flours were held in covered plastic containers at ambient tropical laboratory conditions of 30±2°C and relative humidity of 75±5%. The colours of the prepared flours were also noted.

Sex Determination of *Tribolium castaneum*

To determine the sex of the rust-red flour beetle, *T. castaneum,* the pupal stage of the insect was placed on a slide and viewed under a binocular microscope for the sex characteristics. The sexes were confirmed by observing the genital papillae on the ventral side of the distal abdominal segment. The female pupae possess well developed, protruding genital papillae while the males possess reduced genital papillae compared to females (Parthasarathy*et al.*, 2008).

Insect Rearing

T. castaneum adults were cultured in wheat flour under tropical laboratory conditions of 30±2°C and relative humidity of 75±5%. Each wheat flour was measured into separate containers (250g/container) and 30 adult beetles (♀:♂ = 1:1) were introduced into the medium and covered to prevent possible escape of the beetles. The containers were then kept in the culturing chamber (cage) made of wire gauze to prevent cross infestation. After 7 days, the adult beetles were removed. The culture was observed weekly until teneral adults needed for the subsequent experiments started emerging.

Determination of the Proximate Composition of the Flour Types.

To determine the growth factors in the flours, the nutrient contents such as crude protein, moisture, lipid, ash and crude fibre and carbohydrate were assayed using the official methods of the Association of Analytical Chemists (AOAC, 1990). These analyses were carried out on wheat, sorghum, millet and maize flours, respectively.

Determination of the Mineral Profile of the Four Flour Types

The mineral analyses were carried out on all the samples as follows: One gram (1g) of each sample was ashed in a muffle furnace at 550°C. The ashed sample and dishes were removed and transferred into the desiccator to cool after which the samples were dissolved with 1ml of concentrated HNO_3. Little distilled water was added and filtered into a clean small plastic bottle using Whatman No. 43 filter paper. Distilled water was later used to dilute the solution up to 50ml. Atomic absorption spectrophotometer Buck 210 Model 200 was used in determining the concentration of the metals: Copper (Cu), Iron (Fe), Manganese (Mn), Lead (Pb), Magnesium (Mg), Calcium (Ca) and Zinc (Zn) while sodium (Na) and Potassium (K) were determined by flame photometry.

Anti-Nutrient Analyses of the Flour Media

Anti-nutrient contents were estimated by the bioassay procedures of AOAC (1990) as modified by various authors cited in specific assays. The modified procedure of Day & Underwood (1986) was used to determine the oxalate content. The phytate and saponincontent of the flour types were assayed by protocols described by Obadoni & Ochuko (2001).

The tannin contents were determined using the Folin Denis reagent as described by Makkar *et al.,* (1993). A standard calibration curve was prepared and the absorbance (A) against concentration of tannins at 725nm was estimated.

Effect of the Food Type on the Growth of *Tribolium castaneum*

To determine the effect of food type on the growth of the rust-red flour beetle, an experiment was carried out under ambient tropical laboratory conditions of 30±2°C and 75±5% r.h. Two copulating pair of adult *T. castaneum* were introduced into each of the four replicates of 20g of each of the different food media (i.e wheat, sorghum, maize and millet flours) measured into small plastic containers with the lid perforated and sealed with a muslin cloth to prevent the escape of the insects. The containers were thereafter kept in the culturing chamber (cage) made of wire gauze to prevent cross infestation. The adult beetles were removed after 7 days by sieving the flour with a sieve of $0.5mm^2$ mesh size. The experiment was observed on the 14^{th} day after the introduction of the insects and subsequently on weekly basis until the 56^{th} day for the emergence of larvae, pupae and adults. The flour media were sieved to facilitate the separation of the various life-forms (larva, pupa, adult). The population growth was checked by counting the number of larvae, pupa and adult insects in each replicate of the food media.

Host Preference Studies in *Tribolium castaneum*: Choice and No-Choice Tests

Choice Test

This procedure investigates the feeding preference of *T. castaneum* on each of the flour media namely; wheat, millet, sorghum and maize. This experiment was carried out in 4 replicates. Plastic Petri dishes were divided into four sections with paraffin wax after which 5 g each of the flours were introduced into the individual sections and labelled. Ten adult males and ten females of *T. castaneum* were introduced into the centre of each Petri dish and covered. The Petri dishes were sealed off with a paper tape to prevent the insects from escaping and they were thereafter kept in an insect cage. The insects were allowed to copulate and removed after 7 days. On the fourteenth day, the flour in each section was carefully removed and sieved using 0.05 mm mesh size. The filtrate was then observed under a monocular light microscope to view the number of larva in each section.

No-Choice Test

This test was aimed at investigating the development of *T. castaneum* in four different flour media. This experiment was carried out in 4 replicates. Fine flour was obtained from the four cereal grains used in this experiment. Twenty grams (20 g) of each of the flours was measured into separate Petri-dishes. Ten copulating pairs of adult *T. castaneum* beetles were introduced into the plastic Petri-dishes which then were covered and sealed with paper tape. Other protocols and observations for larval emergence were as described in 'choice test' above.

Statistical Analysis

Data obtained from the proximate analysis, mineral profile and anti-nutrient profile of the four cereal flours tested and the biological activity of *T. castaneum* were subjected to one-way Analysis of Variance (ANOVA) and where significant differences existed, treatment means were compared at 0.05 significant levels using New Duncan's multiple range test (Zar, 1984).

Furthermore, the aforementioned data were also subjected to correlation-regression analysis using the SPSS® 16.0 (2007 version) statistical package to identify if there was any relationship between the chemical composition of the cereal flours and the biological activity of *T. castaneum*.

RESULTS

Colour of the Prepared Flour Types

Table 1 shows the colour of the cereal flours used to rear *T. castaneum*in the course of this study. The colour of the flours ranged from white in maize flour to pink in sorghum flour while whole wheat flour was light brown in appearance and millet flour was grey in colour.

Table 1. The Colours of the Four Cereal Flours Used as Growth Media for *Tribolium castaneum*

Flour type	Colour
Wheat flour	Light brown
Millet flour	Grey
Maize flour	White
Sorghum flour	Pink

Proximate Analysis of the Flour Types

The proximate composition of four cereal flours namely, wheat, maize, millet and sorghum are presented in Table 2. Moisture content was lowest in wheat flour (7.64%) and highest in maize flour (9.24%) followed by sorghum (8.90%) and millet flours (8.48%) respectively. There was no significant difference ($P \geq 0.05$) between the moisture content of sorghum and millet, but significant differences existed between the moisture content of maize and wheat flour.

Wheat flour had the highest protein content (17.23%) while millet flour had the lowest protein content (10.91%). Wheat flour was significantly different ($P<0.05$) from the other flour types (maize, millet and sorghum flour). However, crude protein in maize, millet and sorghum flours were not significantly different ($P>0.05$). Sorghum has the highest fibre content (2.05%), while maize flour has the lowest (1.12%). There were significant differences ($P<0.05$) in the fibre content in the four flour types except for maize (1.12%) and wheat flour (1.16%) that were not significantly different at $P=0.05$.

Table 2: Proximate Composition (%) of Four Flour Types Used as Growth Media for *Tribolium castaneum*

Food media	Moisture	Fibre	Ash	Protein	Fat content	Carbohydrate
Sorghum	[illegible]^{ab} ± 0.36	2.05^{c} ± 0.12	1.65^{a} ± 0.14	11.34^{a} ± 0.26	16.45^{a} ± 1.11	59.61^{a}±1.18
Maize	9.24^{b} ± 0.38	1.12^{b} ± 0.03	1.05^{a} ± 0.10	11.05^{a} ± 0.38	15.11^{a} ± 0.79	62.41^{a} ±1.22
Millet	8.48^{ab} ± 0.38	0.85^{a} ± 0.05	2.59^{b} ± 0.49	10.91^{a} ± 0.55	16.32^{a} ± 1.10	60.85^{a}±1.46
Wheat	7.64^{a} ± 0.53	1.16^{b} ± 0.02	1.42^{a} ± 0.10	17.23^{b} ± 0.95	13.81^{a} ± 0.82	57.34^{a}±2.28

Each value is a mean of triplicate samples ± standard error of the mean. Mean values along a column followed by the same letter(s) are not significantly different at P<0.05 by New Duncan's multiple range test.

Table 3: Mineral Contents of Four Flour Media Used for Biological Studies of Rust-Red Flour Beetle

Flour type	**Concentration of Minerals (ppm)**								
	Ca	**Mg**	**K**	**Na**	**Mn**	**Fe**	**Cu**	**Zn**	**Pb**
Sorghum	4.79^{c}±0.09	15.07^{d}±0.02	39.38^{c}±0.02	0.57^{c}±0.02	0.15^{c}±0.00	0.78^{c}±0.01	2.15^{c}±0.01	0.43^{b}±0.01	0.06^{b}±0.00
Maize	4.13^{b}±0.01	11.55^{b}±0.01	36.35^{a}±0.08	0.45^{b}±0.01	0.07^{a}±0.01	0.38^{a}±0.01	0.36^{b}±0.02	0.35^{a}±0.01	0.02^{a}±0.01
Millet	0.96^{a}±0.02	8.09^{a}±0.00	36.80^{b}±0.01	0.37^{a}±0.01	0.12^{b}±0.01	0.92^{d}±0.01	0.20^{a}±0.01	0.36^{a}±0.01	0.06^{b}±0.01
Wheat	4.67^{c}±0.01	14.13^{c}±0.01	57.56^{d}±0.00	0.55^{c}±0.01	0.55^{d}±0.01	0.69^{b}±0.01	0.23^{a}±0.01	0.40^{b}±0.01	0.05^{b}±0.01

Each value is a mean of four replicate samples ± standard error of the mean. Mean values along a column followed by the same letter(s) are not significantly different at P<0.05 by New Duncan's multiple range test.

Mineral Analysis of Food Media Used as Growth Media for ***Tribolium castaneum***

The highest amount of calcium was recorded in sorghum flour (4.79) while the lowest amount of calcium occurred in millet flour (0.96) (Table 3). The calcium content of the four flour types were significantly different at 5% probability level. Magnesium content was highest in sorghum flour (15.07) and lowest in millet flour (8.09). The magnesium contents were different significantly (P≤0.05) in the four growth media.

Wheat flour had the highest potassium content (57.56) while the lowest potassium content was recorded in maize flour (36.50). All the four flour types showed significant differences in potassium content at P=0.05. Sodium concentration was highest in sorghum flour (0.57), followed by wheat flour (0.55), maize flour (0.45) and millet flour (0.12). There were significant differences in the sodium content of all the flours at P=0.05. Manganese was lowest in maize flour (0.12) and highest in wheat (0.55). The flours were significantly different P≤ 0.05 from each other in terms of manganese content.

The iron (Fe) content in the four flour types was significantly different at P=0.05. The iron content was found to be highest in millet flour (0.92), followed by sorghum flour (0.78), wheat flour (0.69) and the lowest value was obtained in maize flour (0.38).

Sorghum flour had the highest amount of copper (2.15), while the lowest (0.20) was recorded in millet flour. There was no significant difference (P≥0.05) between millet and wheat flours in terms of copper content. However, significant differences existed in the copper content of the growth media at 5% probability level (Table 3). Zinc was highest in sorghum flour (0.43) and lowest in maize flour (0.35). There was no significant difference (P≥ 0.05) in the amount of zinc present in maize and wheat flour. There was also no significant difference (P≥ 0.05) between sorghum and millet flour (Table 3). Table 3 shows that there was no significant difference (P≥ 0.05) in the amount of lead present in sorghum flour, millet flour and wheat flour. However, the lead content of maize flour (0.03) was significantly lower (P≤0.05) than the other flours evaluated.

Table 4: Anti-Nutritional Content (mg/100g) of Four Flour Types Used for Bioassays on *T. Castaneum*

Food media	Oxalate	PhytateSaponin	Tannin	
Sorghum	$0.54^{d} \pm 0.00$	$7.64^{a} \pm 0.53$	$3.46^{b} \pm 0.07$	$0.88^{b} \pm 0.05$
Maize	$0.36^{a} \pm 0.00$	$8.78^{ab} \pm 0.27$	$2.02^{a} \pm 0.04$	$0.77^{b} \pm 0.03$
Millet	$0.47^{c} \pm 0.02$	$9.58^{b} \pm 0.26$	$3.29^{b} \pm 0.02$	$0.49^{a} \pm 0.03$
Wheat	$0.41^{b} \pm 0.00$	$13.31^{c} \pm 0.49$	$3.43^{b} \pm 0.67$	$0.57^{a} \pm 0.03$

Each value is a mean of triplicate samples ± standard error of the mean. Means along a column followed by the same letter(s) are not significantly different at P<0.05 by New Duncan's multiple range test.

Antinutrient Contents of the Four Flour Types Used as Growth Media for *Tribolium castaneum*

The antinutrient contents of all the flour types used in this study is presented in Table 4. The oxalate, tannin and saponin contents were highest in sorghum flour while oxalate and saponin were lowest in maize. Millet (0.49) and sorghum (7.64) had the lowest tannin and phytate contents. Wheat flour had the highest phytate content (13.31) followed by millet flour (9.58) and maize flour (8.78). Wheat flour showed significant difference (P≤0.05) in the phytate content compared to the other flour types.

Sorghum flour had the highest oxalate content (0.54) followed by millet flour (0.47), wheat flour (0.41) and maize flour (0.36). There were significant differences (P≤ 0.05) in the oxalate contents for all four flour types. Sorghum flour had the highest saponin content (3.46) while maize flour had the lowest saponin content (2.02). There was no significant difference (P≥ 0.05) between the saponin content in sorghum, millet and wheat flours whereas, significant differences existed between maize flour and the other flours at P=0.05. Sorghum flour (0.88) has the highest percentage of tannin compared to the other food media (Table 3). There was significant difference (P≤ 0.05) between the tannin content in wheat flour and sorghum flour, and no significant difference (P≥0.05) was obtained between wheat and millet flours. There was also no significant difference between the tannin content in sorghum and maize flour at 5% probability level.

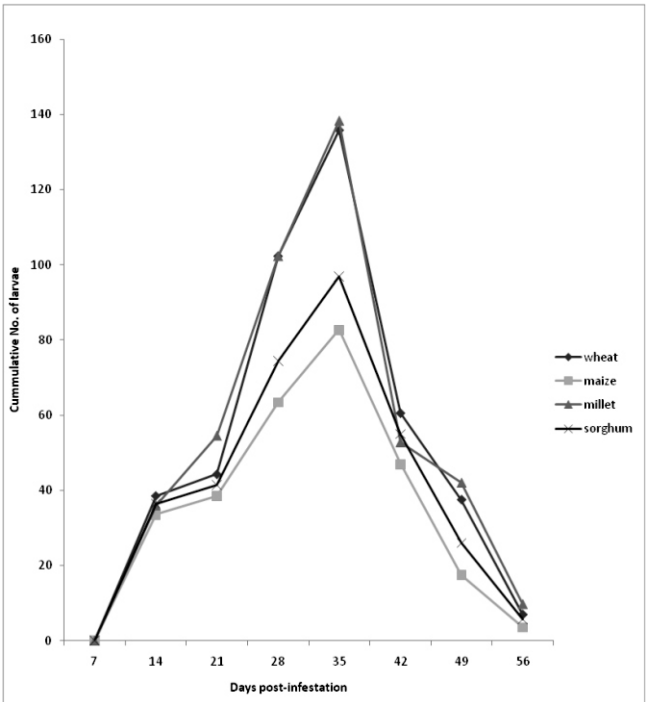

Figure 2: The development of *Tribolium castaneum* larva on four flour types

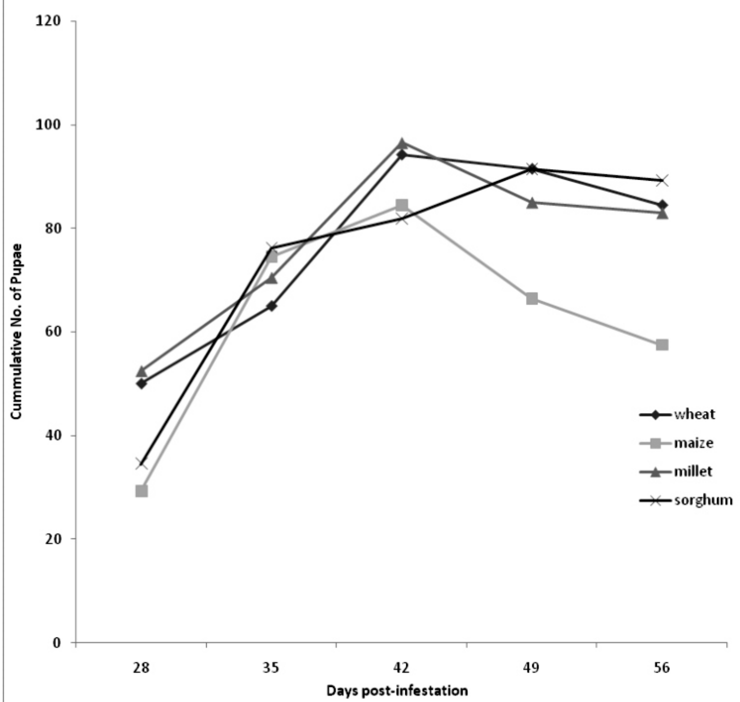

Figure 3: The development of *Tribolium castaneum* pupa on four flour types

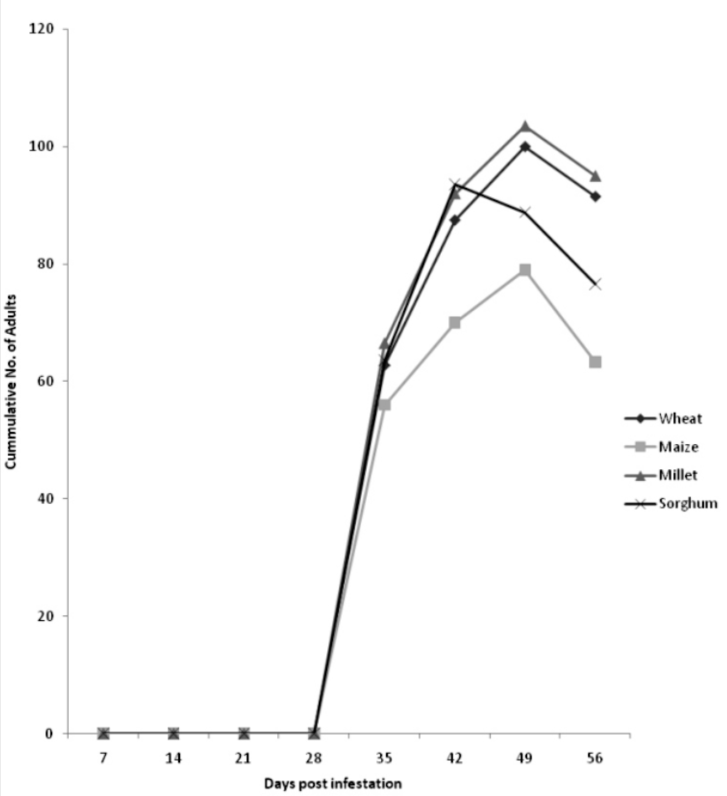

Figure 4: The development of adult *Tribolium castaneum* on four flour types

Table 5: Food Preference of *T. castaneum* in Four Flour Types

Food media	Mean number of larva ± S.E.	
	Choice test	No-choice test
Wheat	63.75^{c} ± 0.48	161.00^{c}± 0.71
Maize	53.75^{a} ± 0.48	142.25^{a} ± 1.10
Millet	65.00^{c} ± 0.41	171.75^{d} ± 0.85
Sorghum	57.00^{b} ± 0.41	156.75^{b} ± 0.48

Each value is a mean of four replicate samples±standard error of the mean. Means followed by the same letter(s) along a column are not significantly different at P<0.05 by Duncan's multiple range test

The Development of *Tribolium castaneum* on Four Flour Types

Larval Development

Larval emergence was first seen in the four flour types on the 14th day (Figure 2). Wheat flour had the highest mean larval count on the 14th day (38.50±0.65), while maize flour had the lowest (33.50±0.65). The highest (435.50±4.96) and lowest (285.25±4.51) mean larval count was observed in millet flour and maize flour respectively. There was no significant difference in the number of larvae in millet flour (36.00) and sorghum flour (36.50) on the 14th day, but the larval count in wheat and maize flours were significantly different (P≤0.05). There were significant differences in the number of larvae in the four growth media on the 21st and 28th day at P= 0.05 (Figure 2).

Pupal Development

Figure 3 shows the average number of *T. castaneum* pupae that emerged in the four cereal flours. There was no record of pupal formation in all the food media until the 28th day. Significant differences existed in the pupal development of the beetle in the four flour types on the 28th day. The highest number of pupae during the 56-day period was recorded in millet flour (387.50±3.90); while the lowest was recorded in maize flour (312.25±3.70).Generally, the four flour types had significant effect on pupal development.

Adult Emergence

The emergence of adult *T. castaneum* from infested flours is presented in Figure 4. No beetle emerged until the 35th day after infestation. On the 56th day post-infestation, millet flour had the highest mean value of adult insects (357.00±2.62) while maize flour had the lowest mean value (268.25±2.32).

Host Preference Studies

Table 5 shows results of the host preference of *T. castaneum* on the four flours investigated. The number of larvae in wheat flour (63.75) was not significantly different ($P \geq 0.05$) from those found in millet flour (65.00), but there was a significant difference ($P \leq 0.05$) in the number of larvae found in maize (53.75) and sorghum flour (57.00).

Correlation between the Development of *T. castaneum* and Antinutrient Content in the Four Flours

From the results of the correlation analysis as shown in Table 6, sorghum flour had a negative correlation with the oxalate (-0.73) and phytate contents (-0.64). There was a negative and non-significant correlation (-0.32) between saponin content and sorghum flour. Also, there was a negative and non-significant relationship (-0.29) between the tannin content and sorghum flour.

Maize flour had a positive and significant correlation (0.75) with the oxalate content while there was a positive but insignificant correlation (0.37) between maize flour and phytate content. The saponin content was positively correlated with maize flour (0.57). Similarly, there was a positive correlation between tannin content and maize flour (0.70). Oxalate content and millet flour were negatively correlated (-0.18). The phytate content was negatively correlated with millet four (-0.37). Millet flour and saponin content were positively correlated (0.13). The tannin content and millet flour were positively correlated (0.25) but not significant. There was a negative correlation (-0.78) between wheat flour and oxalate content. There was a positive correlation (-0.77) between wheat flour and phytate content. Similarly, there was a negative correlation (-0.95) between saponin and wheat flour. There was also a negative correlation between the tannin content (-0.95) and wheat flour.

DISCUSSION

All the cereal grain flours evaluated in this study contained ample nutrients to support the growth and development of the rust-red flour beetle, *T. castaneum*. It is also evident from this study that there are wide variabilities between the different flours tested with respect to the number of larvae, pupae and F_1 adults that emerged, level of susceptibility and feeding preference. These taken together reflect the ability of particular cereal flour to resist pest attack.

The moisture content of any food is an index of its water activity and is used as a measure of stability and the susceptibility to microbial contamination (Okaraonye and Ikewuchi, 2009). Makanjuola *et al.* (2009) reported that the low moisture content of rice was a likely factor that conferred susceptibility to rice cultivars in storage. The moisture contents recorded for all the flours used in this study were in the safe moisture range as listed by Hayma (1995).

Carbohydrates serve as a source of energy and may be converted to fats for storage and to amino acids (Chapman, 1980). The number of adults reduced as the development period progressed because there was no replenishment of the food media. Chapman (1980) also reported that *Tribolium* uses starch, alcohol, trisaccharides, disaccharides and monosaccharides. Behmer

(2006) reported that the flour beetle, *Tenebrio*, exhibits optimal growth on diets containing 70% carbohydrate. *Tenebrio* fails to develop however, if the carbohydrate concentrations drop below 40%. Carbohydrates are the major sources of metabolic energy for plant-feeding insects. From the results of this study, the concentration of carbohydrate in the flours used in culturing *T. castaneum* ranged from 57.34% in wheat flour to 62.41% in maize making the flours suitable for the growth and development of *T. castaneum*.

Maize, wheat and sorghum flours had a similar ash content which was significantly lower in millet, which might be responsible for the susceptibility of millet flour to *T. castaneum*.

The sodium content in millet was low (0.37±0.01) when compared to maize, millet and sorghum flours. This might be due to variation in soil types (Bulus, 2008). Millet flour was also high in iron. All the flours used in this study had very low lead content.

Ramputh *et al.* (2002) reported that significant relationship between grain damage and soluble phenolic content had a cause-and-effect relationship. They also reported that phenolics are well known to be directly involved in insect resistance in many plants by antixenosis and antibiosis. Adesuyi (1979) reported that factors responsible for the resistance of stored products to insects such as *Tribolium* spp. included presence of toxic alkaloids or amino acids, insect feeding deterrents, seed coat characteristics, digestive enzyme inhibitors and kernel hardness. Susceptibility of millet flour could be ascribed to the low levels of anti-nutrients. Alkaloids, flavonoids, saponins and tannins are known to have antimicrobial activity as well as other physiological activities. Many of the complexes formed by phytate with metallic ions are relatively insoluble; this accounts for a decrease in intestinal absorption of minerals (Spivey Fox and Tao, 1989). Veillon (2011) identified 2-deoxy-D-galactose, myo-inositol and phytate as potential termiticides. These compounds showed promise as potential control chemicals in the control of subterranean termites, *Coptotermes formosanus*. The negative correlation of oxalate (-0.18) and phytate (-0.37) in millet compared with oxalate (0.75) and saponin (0.37) in maize is probably responsible for the significant reproductive success obtained in millet flour. The phytate content in wheat flour was highest in comparison to the other flours tested. Therefore, it thus appears that phytate was not a limiting factor in the growth and development of *T. castaneum*.

The results obtained showed that millet flour was the most susceptible to *T. castaneum* because it recorded the highest number of larvae (138.25 ± 0.85), pupae (96.50 ± 0.41) and adults (103.50 ± 0.65) through the 56-day experimental period. The highest number of larvae was also recorded in millet flour in both the choice (65.00 ± 0.41) and no-choice tests (171.75 ± 0.85).The larval emergence of *T. castaneum* was observed on the 14th day for all four flours used in the experiment. This agrees with Bulus (2008) that the emergence of *T. castaneum* larva may take up to 8-12 days depending on the environmental condition.

Pupae emerged on the four substrates under the same environmental condition after 21 days of infestation. This is in agreement with the report of NRI (1996) that the pupal stage of *T. castaneum* takes between 3-4 weeks on a suitable substrate. *Tribolium castaneum* reared on the four cereal flours completed their development in 35 days. This is in agreement with the findings of Bulus (2008).

Insects show colour preference mostly to those which resemble foliage, flower, or their hosts (Reza and Parween, 2006). Lobdell *et al.* (2005) observed that the egg parasitoid *Trichogramma ostriniae* showed differential responses to egg colour or the hosts as well as the background colour in the Petri-dish arena while searching for food. Generally, a wide range of insects exhibit attraction towards yellow colour. The Coccinellidae, Curculionidae and Scaraberidae showed preference for yellow traps as observed by Cross *et al.* (1976). The colour of the cereal flours used in this study ranged from pink in sorghum to white in maize; millet was grey in colour while wheat flour was light-brown in colour. Reza and Parween (2006) reported that adult *T. castaneum* showed no preference for coloured or white surfaces except for black. The results from the choice and no-choice test revealed that *T. castaneum* had preference for millet flour probably because of its grey colour. It is evident from this study that other factors apart from the antinutrient profile conferred resistance to maize flour.

Millet flour was the most susceptible to *Tribolium* infestation and was closely followed by wheat and sorghum. The least susceptible was maize flour. The presence of tannin and other anti-nutrients inhibited the growth of the *T. castaneum*. This is responsible for the reduced growth performance of the beetle in sorghum and maize flours when compared with wheat and millet flours.

Storage losses are becoming more serious as more countries achieve self-sufficiency in cereal production. Host plant resistance to storage insects is a potential means of reducing post-harvest losses of stored cereals and it is therefore recommended. The importance of anti-nutrients as a resistance factor for cereal flours needs to be verified and possibly included as a breeding objective.

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