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SUSCEPTIBILITY OF FLOURS DERIVED FROM VARIOUS CEREAL GRAINS TO INFESTATION BY THE RUST-RED FLOUR BEETLE (*TRIBOLIUM CASTANEUM* HERBST) (*COLEOPTERA*: *TENEBRIONIDAE*) IN DIFFERENT SEASONS

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Abstract: Two flour types (unpolished flour and polished one) and flour textures (grits and fine) of five cereal grains made up of millet, rice, wheat, sorghum and maize were evaluated under laboratory conditions for their susceptibility and progeny development in *Tribolium castaneum* in hot dry and cool humid seasons. *T. castaneum* thrived better during the cool humid season than the hot dry season. Polished flour was less susceptible to infestation and supported lower population of the beetles than unpolished flour. Index of susceptibility was 19.65–20.76% in unpolished flour and 18.89–19.76% in polished flour. The number of progeny that developed were 102.6–135.1 and 98.2–121.4 in unpolished and polished flours, respectively. Similarly, grit flour was significantly less susceptible than fine flour in both seasons. Rice, wheat and sorghum flours were less susceptible and supported significantly lower populations of *T. castaneum* than millet and maize flours in both seasons. Polished wheat flour supported least progeny number than the flour types of the other cereal grains. Conversely, significantly higher number of progeny developed in polished flour of millet and maize and unpolished flour of wheat. Millet fine flour and maize fine or grit flours were significantly more susceptible to infestation than flours of the other cereal grains.

Key words: susceptibility, cereal, flour, *Tribolium castaneum*, season

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INTRODUCTION

Cereal grains are major staple foods in Nigeria. The grains are processed by dehulling into fine flour or grits (Nkama and Malleshi 1998). Grains milled into flours could intensify the activity of secondary pests in storage (Haines 1991). The rust-red flour beetle *Tribolium castaneum* (Herbst) is a serious secondary storage pest of flours of all the important cereals in Nigeria namely maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], wheat (*Triticum aestivam* L.), rice (*Oryza sativa* L.) and millet [*Pennisetum glaucum* (L.) R. Br.]. *T castaneum* infestation could directly result in weight loss and the beetle indirectly imparts a brownish tinge and pungent smell to infested flour by secretion of benzequinones (Appert 1987; Hodges *et al.* 1996).

Comprehensive work had been carried out on the biology (Dawson 1964; Howe 1966; Wool 1969; Osuji 1984; NRI 1996) and behaviour (Suzuki 1980; Williams *et al*. 1982; Longstaff 1995) of *T. castaneum*. In the recent times some aspects of the biology of *T. castaneum* on local Nigerian grown cereals have been also studied (Lale and Yusuf 2001; Lale *et al*. 2002; Lale and Sastawa 2004). However, information on the susceptibility of flours of different local cereals to *T. castaneum* is not sufficiently available in the literature. This work therefore, investigated flours from different cereals as food sources for the pest in order to identify cereal types of grains that might give flours with resistance to development of *T. castaneum* in storage and to determine the effects of polishing and flour texture on *T. castaneum* development.

MATERIALS AND METHODS

The experiment was conducted in the Crop Protection Laboratory of the Faculty of Agriculture, University of Maiduguri during the hot dry season (March–April: 32.9 ±2.13°C, 24.3 ±10.9% RH) and the cool humid season (July–August: 26.9 ±1.86°C, 71.7 ±9.53% RH).

Sources of grains and flour preparation

Millet (Ex-Borno), sorghum (ICSV 111), wheat (SERI M82) and maize (TZESR-W) grains were obtained from the germplasm of the Lake Chad Research Institute, Maiduguri. Rice (Dan Gote®) was procured from a commercial source in Maiduguri. One kilogram of each grain was divided into two portions, one portion dehulled and milled into polished flour of either grit or fine texture, and the other portion was milled with its hull (unpolished flour or whole meal flour) also into grit and fine flours. Dehulling was done at Lake Chad Research Institute, Maiduguri using a Mc Gill® No. 3 dehuller for 5 minutes, while milling was done using a Brabender Miller (Quadrumat® Senior).

Establishment and maintenance of stock culture of *T. castaneum*

T. castaneum culture was established on maize flour and maintained throughout the period of the study in the laboratory. Culture methods entailed placing 100 females and 50 males in a 500 ml plastic jar containing of 300 g maize flour mixture of grits and fine flours at the ratio of 2:3. At first larval emergence, samples were sieved daily and the larvae transferred, using an aspirator, onto fresh flour weighing 100 g and allowed to develop to adults, which were then removed and kept in small containers containing 50 g of maize flour for further use. Males and females were sexed according to Odeyemi (2001).

Experimental procedure and design

Factorial experimental design was used to assess the effects of processing and texture of the different cereal flours on the population of *T. castaneum.* The factorial treatments comprised of grain types (maize, sorghum, millet, rice and wheat), flour texture (grits (150 μ) and fine (532 μ) and flour type (unpolished flour and polished flour) assigned as main factor, sub-factor and sub-sub factor treatments, respectively.

Infestation procedure

For each treatment 5 males and 5 females adults were introduced into the centre of a 90-cm-diameter Petri dish on 20 g of the flour products. Top of the Petri dishes were screened with fine mesh to prevent escape of insects and allow for aeration. The parent beetles were removed after 14 days of oviposition period. The experiment was terminated after 40 days.

Data collection and analysis

For each treatment, the number of larvae, pupae and adults that developed on each of the sample was counted after 40 days. Index of susceptibility (SI) of the flours to infestation by *T. castaneum* was computed as described by Dobie (1974) as follows:

$$SI = \frac{Log_e F_1}{D} x\, 100\%$$

where: F_1 – the total number of emerging adults,
D – the median developmental period, estimated from the middle of oviposition period to the emergence of 50% of the F_1 generation.

The data collected were subjected to analysis of variance (ANOVA) and treatment means were separated using a Student Newman Keuls Test at 5% level of probability.

RESULTS

Table 1 shows that the susceptibilities of unpolished and polished flours to infestation by *T. castaneum* were comparable during the hot dry season. Conversely, polished flour was less susceptible than unpolished flour to beetle infestation during the cool humid season. Grit flour was less susceptible than fine flour to beetle infestation in both the hot dry and cool humid seasons. In respect of the grain types, rice, wheat and sorghum flours were significantly less susceptible to beetle infestation than millet and maize flours in both seasons; however, rice flour exhibited greater susceptibility than sorghum and wheat in the cool humid season, thought there was no such difference in the hot dry season. Both flour type and texture had significant effect on susceptibility, but there was no significant difference ($p > 0.05$) between the two. However, significant interaction ($p < 0.01$) was observed between flour type and grain type in both seasons.

Table 1. Susceptibility of flours of different cereal grains to infestation by *T. castaneum* during the hot dry season (March–April; 32.9 ±2.13°C and 24.3 ±10.9% RH) and cool humid season (July–August; 26.9 ±1.86°C and 71.7 ±9.5k3% RH) in Maiduguri

Treatment	Seasons	
	hot dry	cool humid
Flour type (A)		
Unpolished flour	19.65 a	20.76 a
Polished flour	18.98 a	19.76 b
SE±	0.17	0.26
Flour texture (B)		
Grit (532 µ) flour	18.49 b	19.68 b
Fine (150 µ) flour	20.14 a	20.9 a
SE±	0.17	0.36
Grain type (C)		
Millet	21.29 a	21.89 a
Rice	18.58 b	20.09 b
Wheat	18.37 b	18.63 c
Sorghum	17.66 b	18.08 c
Maize	20.68 a	22.76 a
SE±	0.45	0.33
Interaction		
A x B	n.s.	n.s.
A x C	**	**
B x C	n.s.	*
A x B x C	n.s.	*

Means of treatment combinations followed by the same letter within a column are not significantly different using Student Newman Keuls Test at p = 0.05
n.s. – not significant at p = 0.05
** significant at p = 0.01
* significant at p = 0.05

The effect of flour type (unpolished or polished) on susceptibility to infestation significantly varied between grain types and seasons (Table 2). In the hot dry season polished flours of maize, millet and unpolished wheat flour were more susceptible, while least susceptible was wheat polished flour. In the cool humid season, though the index of susceptibility (SI) across all treatments were arbitrarily higher than in the hot dry season. A more or less similar trend was observed with flours of polished and unpolished maize and that of polished millet being more susceptible; polished wheat flour being least susceptible to infestation.

Table 2. Susceptibility of different grains and flour types to infestation by *T. castaneum* during the hot dry season (March–April; 32.9 ±2.13°C and 24.3 ±10.9% RH) in Maiduguri

Treatment	Hot dry season	Cool humid season
Millet x unpolished flour	20.97 ab	21.67 bc
Millet x polished flour	21.61 a	22.10 b
Rice x unpolished flour	17.85 cd	19.74 de
Rice x polished flour	19.30 bc	20.44 cd
Wheat x unpolished flour	21.28 a	21.40 bc
Wheat x polished flour	15.46 e	15.85 g
Sorghum x unpolished flour	18.06 cd	18.88 e
Sorghum x polished flour	17.27 d	17.28 f
Maize x unpolished flour	20.09 ab	22.12 ab
Maize x polished flour	21.27 a	23.40 ab
SE±	0.65	0.46

Means of treatment combinations followed by the same letter within a column are not significantly different using Student Newman Keuls Test at p = 0.05

There were significant differences in the combined effects of flour texture and grain type on susceptibility of flours obtained from different grains. Table 3 shows that grit flour obtained from sorghum was least susceptible, while fine flour obtained from millet or maize as well as maize grit flours were most susceptible. Rice grit flour did not significantly differ from fine flours of wheat and sorghum possessing intermediate level of susceptibility.

Results of the analysis of effects of flour type, flour texture and grain type on *T. castaneum* progeny production are shown in Table 4. In general more progeny were produced in the cool humid than in the hot dry season. However, there were significant differences ($p < 0.05$) between treatments within seasons. More progeny were produced on unpolished than polished flour. Indeed polishing reduced progeny number by 4.3 and 10.1% in hot dry and cool humid seasons, respectively. Similarly, higher number of progeny developed on fine flour than on grit flour. Ranking for progeny number across all grain types was consistent, thus maize and millet > rice, wheat and sorghum. It was also indicated that significant interaction was observed only between flour type and grain type in both seasons.

There was significant interaction between the grain type and the type of flour obtained from the grain on the population of *T. castaneum* during both seasons (Table 5). Fewer insects developed in polished wheat flour than in any flour type of the other cereal grains, except unpolished rice flour during the hot dry season and unpolished rice flour and polished sorghum flour during the cool humid season. In contrast, irrespective of the flour type, the population of *T. castaneum* was significantly higher in flours of millet and maize than in flours of all other grains during both seasons, with

Table 3. Susceptibilities of different diet forms (flour texture x grain type) to infestation by *T. castaneum* during cool humid season (July–August; 26.9 ±1.86°C and 71.7 ±9.53% RH) in Maiduguri

Grain type	Flour texture	
	Grit	Fine
Millet	20.72 b	23.06 a
Rice	19.56 bc	20.63 b
Wheat	18.41 c	18.84 c
Sorghum	16.95 d	19.22 c
Maize	22.78 a	22.74 a
SE±	0.50	0.46

Means of treatment combinations followed by the same letter are not significantly different using Student Newman Keuls Test at p = 0.05

Table 4. Effects of flour type, flour texture and cereal type on mean number of *T. castaneum* during the hot dry season (March–April; 32.9 ±2.13°C and 24.3 ±10.9% RH) and cool humid season (July–August; 26.9 ±1.86°C and 71.7 ±9.53% RH) in Maiduguri

Treatment	Seasons	
	hot dry	cool humid
Flour type (A)		
Unpolished flour	102.6 a	135.1 a
Polished flour	98.2 a	121.4 b
SE±	2.20	4.11
Flour texture (B)		
Grit (532 μ) flour	90.1 b	117.5 b
Fine (150 μ) flour	110.7 a	139.0 a
SE±	3.82	4.98
Grain type (C)		
Millet	152.9 a	182.6 a
Rice	66.3 b	93.3 b
Wheat	67.7 b	97.7 b
Sorghum	76.7 b	89.3 b
Maize	138.5 a	178.4 a
SE±	6.87	7.67
Interaction		
A x B	n.s.	n.s.
A x C	**	**
B x C	n.s.	n.s.
A x B x C	n.s.	n.s.

Means within a column followed by the same letter within a column are not significantly different using Student Newman Keuls Test at p = 0.05
n.s. – not significant at p = 0.05
** significant at p = 0.01

Table 5. Interaction effects of flour type and grain type on mean number of *T. castaneum* during the hot dry season (March–April; 32.9 ±2.13°C and 24.3 ±10.9% RH) in Maiduguri

Treatment	Hot dry season	Cool humid season
Millet x unpolished flour	149.5 a	187.0 a
Millet x polished flour	156.3 a	178.2 a
Rice x unpolished flour	59.7 cd	82.5 cd
Rice x polished flour	73.0 bc	104.2 c
Wheat x unpolished flour	91.0 b	140.2 b
Wheat x polished flour	41.3 d	55.2 d
Sorghum x unpolished flour	78.3 bc	97.2 c
Sorghum x polished flour	75.0 bc	81.3 cd
Maize x unpolished flour	131.7 a	168.8 ab
Maize x unpolished flour	145.3 a	188.0 a
SE±	9.70	10.9

Means of treatment combinations followed by the same letter within a column are not significantly different using Student Newman Keuls Test at p = 0.05

the exception of unpolished flours of maize and wheat during the cool humid season where population numbers were similar. Flours of rice and sorghum were comparable irrespective of flour type; however, flours obtained from sorghum supported relatively higher beetle population during hot dry season and lower population during the cool humid season: beetle population was higher in the cool humid season in flours of both rice and sorghum.

DISCUSSION

Variability in susceptibility to infestation by *T. castaneum* was observed among flours of the different cereal grains and between the different seasons. Unpolished flour supported higher population of *T. castaneum* during the cool humid season. Unpolished flour of cereal grains, on the average, supported higher population of *T. castaneum* (Haines 1991; Lale and Yusuf 2001), with susceptibility of the flour in order of millet > maize > sorghum > wheat (Lale *et al*. 2002). Millet is grey in colour and has less bran while maize is large in size and has low levels of phenolic compounds (Nkama and Ikwelle 1998). Low tannin improves nutrient availability of plant products by protecting proteins from bacterial degradation and making them available for absorption (Reid *et al*. 1974). This may explain why polished flour of millet and maize supported higher population of *T. castaneum*. On the other hand, bran contains some essential nutrients (Nkama and Malleshi 1998) and has been implicated in supporting higher population of *T. castaneum* in whole flour than polished flour (Lale *et al*. 2002). The result suggests that, on average, flour from maize and millet grains were more susceptible to *T. castaneum* in this agroecology.

Fine flour of maize and millet supported higher population of *T. castaneum* than grit flour in both seasons. It has been reported that *T. castaneum* prefers fine flour for development (Sokoloff *et al*. 1966; Guinner *et al*. 1990; Hill and Walker 1990; Haines 1991; Via 1991; Walker 1992; Odeyemi 2001). Since *T. castaneum* is a secondary pest and this may be responsible for the preference for fine than grit flour for development. The implication is that maize and millet grains processed into fine flour is likely to enhance the development and survival of *T. castaneum*. In contrast, sorghum has high phenolic compounds and there are there are relatively higher amounts of these compounds in wholegrain than decorticated grain (Eggum *et al*. 1982) and these compounds confer resistance to flours of sorghum from storage products beetles (Ramputh *et al*. 1999). Nevertheless, high tannin sorghum may fail to confer resistance to feeding pest species (Butler 1982). This may be responsible for the significantly higher population of *T. castaneum* in whole flour of sorghum and wheat during the hot dry season. Lale and Sastawa (2004) recorded higher population of *T. castaneum* in sorghum cultivar Chakalari-red than Chakalari-white. In contrast, there was significantly lower population of *T. castaneum* in unpolished flour of rice during the hot dry season. Toxic metabolites and benzoquinones secreted by *T. castaneum* to flour medium and intraspecific competition and cannibalism prevalent in *T. castaneum* may have decimated the beetle population in whole flour of rice during the hot dry season (Hodges *et al*. 1996; Haines 1991). High temperature during the hot dry season is favourable for high fecundity in *T. castaneum* (Howe 1966), however, it causes low growth rate in the beetles (King and Dawson 1971).

Conversely, polishing improves digestibility of polished products (Johnson *et al*. 1994). However, high digestibility of food is not always accompanied by higher growth rate particularly in cases where most nutrients are used for maintaining body weights (Nkama and Ikwelle 1998). This may explain why polished flour of sorghum, rice and wheat supported significantly lower population of *T. castaneum* during the cool humid season. Polished flour has lower nutritional value than whole flour (Lale and Sastawa 2004) because polishing reduces the available essential nutrients required for successful growth and development of pest species (Eggum *et al*. 1981; Johnson *et al*. 1994). The implication is that low nutritional value of polished flour is likely to considerably reduce progeny development during the cool humid season than hot dry season (Haines 1991). In addition, tightly packed flour reduce development of eggs laid by *T. castaneum* (Campbell and Hagstrum 2002) and may have reduced the number of the beetles that developed in flour to a greater extent more than in polished than whole flour.

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POLISH SUMMARY

PODATNOŚĆ MĄKI OTRZYMANEJ Z RÓŻNYCH ZIAREN ZBÓŻ NA ZAKAŻENIE PRZEZ *TRIBOLIUM CASTANEUM* (HERBST) (*COLEOPTERA*: *TENEBRIONIDAE*) W RÓŻNYCH SEZONACH

Dwa rodzaje mąki (wyborowa i niskiej jakości) oraz tekstur mąki (kaszki i spożywcza) otrzymanych z pięciu gatunków ziarna, tj. prosa, ryżu, sorgo i kukurydzy zbadano w warunkach laboratoryjnych pod względem ich podatności na wniknięcie *Tribolium castaneum* i rozwój jego potomstwa w porach chłodnej i wilgotnej oraz gorącej i suchej. *T. castaneum* rozwija się lepiej podczas pory chłodnej niż gorącej. Mąka wyborowa jest mniej podatna na zasiedlenie i mniejsza ilość potomstwa w niej się rozwija niż w mące niskiej jakości. Indeks podatności wynosił 19,65–20,76 w przypadku mąki niskiej jakości i 18,89–19,76 dla mąki wyborowej. Liczba rozwiniętego potomstwa wynosiła dla mąki niskiej jakości i wyborowej odpowiednio 102,6–135,1 i 98,2–121,4. Podobnie kaszki były znacząco mniej podatne niż mąka spożywcza w obu sezonach. Mąki ryżowa, pszenna i z sorgo były znacząco mniej podatne i zawierały mniejszą populację *T. castaneum* niż mąka z prosa lub kukurydzy w obu sezonach. Mąka wyborowa pszenna zawierała mniej potomstwa owada niż mąki z innych zbóż. Znacząco więcej potomstwa rozwinęło się w mące wyborowej z prosa i kukurydzy oraz pszennej niskiej jakości. Mąka spożywcza z prosa i kukurydzy lub kaszki były bardziej podatne na zasiedlenie niż mąki z innych ziaren zbóż.