INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
08–069/SAE/2009/11–2–158–162
http://www.fspublishers.org

Full Length Article

Effects of Resource Conditioning, Season and Intraspecific Interaction on Progeny Development in *Tribolium castaneum*

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ABSTRACT

Laboratory experiments were conducted during the cool humid (July/August: 26.5±1.96°C, 64.5±9.81 RH) and hot dry (March/April: 31.1±3.14°C, 18.9±1.11% RH) seasons in Maiduguri (Nigeria) to assess the effects of changing quantities of millet flour on the development of *Tribolium castaneum*. The treatments consisted of four initial quantities of 40, 20, 10 and 5 G millet flour and further additions of none, half and equal quantity to each of the initial quantities, 40 days after infestation (DAI). The population of *T. castaneum* in 40 G flour or when increased was significantly lower 40 DAI and significantly higher 80 DAI than 10 or 5 G flour treated similarly during both hot dry and cool humid seasons. There was a positive correlation between mortality (k-value) in *T. castaneum* and available resource for every *T. castaneum* beetle and a negative relationship between mortality and storage period during both seasons.

Key Words: Season; Resource conditioning; Progeny development; *T. castaneum*

INTRODUCTION

Cereal grains are important sources of nutrition especially in Africa and Asia. In Nigeria, the grains are usually processed into fine or grit flour, which is infested by its major insect pest, *Tribolium castaneum* Herst (Coleoptera: Tenebrionidae) in storage (Haines, 1991).

Development in *T. castaneum* is influenced by temperature and quality of diet it infests (Haines, 1991; Lale *et al.*, 2000), and in flour the quality is inadvertently determined by the form into which the flour is processed. Apart from direct damage, which leads to reduction in weight of infested flours (Sokoloff, 1972; Haines, 1991; Arnaud *et al.*, 2002), *T. castaneum* imparts a brownish tinge and pungent smell on the flour of cereal grains (Appert, 1987). Direct mixing of new and old stocks of grains or grain products in the same warehouse are common features of storage practices in tropical warehouses. In Maiduguri (characterized by distinctively cool humid, cool dry & hot dry seasons) grain merchants restock any time new supply becomes available regardless of the fluctuating seasonal time periods. Likely impact of this practice on the activities of *T. castaneum* is scarcely investigated previously. In this study, the effects of different quantities of millet flour and that of possible increases in the quantities during storage were assessed on the development of *T. castaneum* and its implications for the management of the beetles.

MATERIALS AND METHODS

The experiment was conducted under laboratory conditions during the hot dry (March/April: 31.1±3.14°C, 18.9±1.11% RH) and repeated during the cool humid (July/August: 26.5±1.96°C, 64.5±9.81 RH) seasons in Maiduguri, Nigeria. There were two factors: initial quantities of millet flour of 40, 20, 10 and 5 G and food addition (further added food or food increase) of none, half and equal quantity added to each of the initial quantities, giving a total of 12 treatment combinations. A culture of *T. castaneum* was maintained on millet (cv: Ex-Borno) under similar conditions. Grains of millet cultivar Ex-Borno, obtained from the Lake Chad Research Institute, Maiduguri, were processed into fine flour and used for the study.

During the hot dry season, three portions of each of the initial quantities of 40, 20, 10 and 5 G of the processed millet flour were weighed into 9.0 cm petri-dish. Five pairs of 3-days old adults of *T. castaneum* were introduced into each petri-dish to achieve mating and female oviposition; males of *T. castaneum* were distinguished from the females based on their relative sizes (males are smaller than females) and/or by the presence of a hairy puncture on the ventral surface of the anterior femur (Odeyemi, 2002). These parental adults were removed after 14 days of oviposition. Each treatment was replicated four times and arranged in randomized complete block design. Forty days after infestation (DAI), the numbers of larvae, pupae and adult

To cite this paper: Sastawa, B.M., J.M. Turaki, B.G.J. Kabir and N.E.S. Lale, 2009. Effects of resource conditioning, season and intraspecific interaction on progeny development in *Tribolium castaneum*. *Int. J. Agric. Biol.,* 11: 000–000

progenies (F_1) that developed in each petri-dish (of each category of 40, 20, 10 & 5 G flour) were carefully counted. Thereafter, each petri-dish was given further additions of either zero, half or equal quantity of fresh millet flour; the ratio of initial quantity of flour in a petri-dish to added flour being 1:0 (no flour added to the initial quantity, 1:0.5 (half the amount of the initial quantity of flour added) and 1:1 (equal the amount of the initial quantity of flour added).

Counts of larvae, pupae and adult progenies were separately taken at 60 and 80 DAI (F_2). The following data were also computed for each treatment: resource (flour) (G) per *T. castaneum* (as amount of resource (G)/number of *T. castaneum*); number of *T. castaneum* per gram of resource (as number of *T. castaneum*/amount of resource); percent change in the population of each life stage of *T. castaneum* (as final population of each life stage of *T castaneum* 80 DAI - initial population of the life stage of *T. castaneum* 40 DAI x 100/final population of the life stage of *T. castaneum*) and larval and pupal mortality (k-value) in *T. castaneum* (as log number of larvae+Pupae–log number of adults). Similar procedure was followed for collecting data during the cool humid season.

Data were subjected to two-way analysis of variance and significant differences between treatment means were determined using the LSD test at P<0.05. Plots of data on percentage change in population of each life stage of *T. castaneum* with diet and on mortality of *T. castaneum* larvae and pupae with changing population were obtained after averaging the data over the seasons.

RESULTS

Table I shows that, 40 DAI had significantly higher number of *T. castaneum* progeny (F_1 population) developed in initial food of 40 G flour than in 20, 10 and 5 G flour during the hot dry season and 10 and 5 G flour during the cool humid season. Differences in initial quantity of food had no significant effect on both the mean number of *T. castaneum* that developed in each gram of flour and the quantity of flour available to each *T. castaneum*.

In contrast, at 80 DAI the population of *T. castaneum* (F_2 population) was significantly higher in initial food of 40 G flour than 20, 10 and 5 G flour and significantly lowers in 5 G flour than 20 and 10 G flour during both the hot dry and cool humid seasons (Table II). Similarly, *T. castaneum* population was significantly higher in food quantities that were doubled the initial quantity and significantly lower in those that were not increased than the population in the other treatments during both seasons. Interaction effects show that 40 G flour that was increased by half or equal quantity during the cool humid season or by equal quantity during the hot dry season supported significantly higher population of *T. castaneum* than other treatments. In the other treatments population of insects differed significantly. During the hot dry season treatments consisting of 40G food, 40G food that supplemented by half the initial quantity and that of 20G supplemented by the same quantity supported larger insect population than treatments consisting of 20G that was supplemented by half and 10G supplemented by the same amount. In the cool humid season 40G food supplemented by half and 20G food supplemented with the same quantity supported higher T. casteneum population than 20G that was supplemented by

Table I. Effects of changes in quantity of food on mean number of of *T. castaneum during the hot dry (31.1 ± 3.14°C, 18.9 ± 1.11% RH) and cool humid (26.5 ± 1.96°C, 64.5 ± 9.81% RH) seasons**

Initial food quantity (G)	Mean no. of F_1 progeny of initial quantity of food	Mean no. of F_1 progeny of G of initial food	Amount of initial food (G)/F_1 progeny
		Hot dry	
40	87.8	3.7611	0.3696
20	65.8	3.8264	0.4480
10	56.6	3.2983	0.7445
5	43.4	3.9861	0.3524
Mean	63.4	3.7180	0.4786
		Cool humid	
40	134.1	5.1806	0.2720
20	113.1	5.2500	0.2949
10	83.9	5.4469	0.2263
5	58.4	5.0278	0.2759
Mean	97.4	5.2263	0.2673

Hot dry season: SE± = 7.95, LSD = 22.52 (F_1-population/initial quantity of food); SE± = 0.15, LSD = Ns (Food quantity (G)/individual of F_1-population); SE± = 0.59, LSD = Ns (F_1-population/G of food).
Cool humid season: SE± = 12.21, LSD = 34.59 (F_1-population/initial quantity of food); SE± = 0.05, LSD = Ns (Food quantity (G)/individual of F_1-population); SE± = 0.69, LSD = Ns (F_1-population/G of food).
* Counts were taken 40 days after infestation (DAI)

Table II. Effects of food supplementation on the mean number of *T. castaneum* during the hot dry (31.1 ± 3.14°C, 18.9 ± 11.1% RH) and cool humid (26.5 ± 1.96°C, 64.5 ± 9.81% RH) seasons

	Mean number of F_2 progeny			
Initial food	Food quantity added to the initial after 40 days of infestation i.e., after emergence of F_1-progeny			
quantity (G)	None	Half	Equal	Mean
		Hot dry		
40	531.0 (40G)**	870.5 (60G)	1279.7 (80G)	893.7
20	248.7 (20G)	348.2 (30G)	746.8 (40G)	447.9
10	239.3 (10G)	276.3 (15G)	531.7 (20G)	349.9
5	103.8 (5G)	138.5 (7.5G)	159.3 (10G)	133.9
Mean	280.7	408.4	679.4	
		Cool humid		
40	787.3 (40G)	1376.5 (60G)	1440.3 (80G)	1201.4
20	359.3 (20G)	554.2 (30G)	806.7 (40G)	573.4
10	275.5 (10G)	330.0 (15G)	642.3 (20G)	415.9
5	146.8 (5G)	164.5 (7.5G)	195.0 (10G)	168.8
Mean	392.3	606.3	771.1	

Hot dry season: SE± = 40.98, LSD = 116.14 (Food quantity added); SE± = 47.32, LSD = 134.1 (Initial food quantity); SE± = 81.96, LSD = 232.27 (Interaction).
Cool humid season: SE± = 55.14, LSD = 156.26 (Food quantity added); SE± = 63.67, LSD = 180.44 (Initial food quantity); SE± = 42.22, LSD = 199.65 (Interaction).
* Counts were taken 80 days after infestation (DAI).
** Quantity of food

Table III. Effects of food supplementation mean number of *T. castaneum/g of flour during the hot dry (31.1 ± 3.14°C, 18.9 ± 11.1% RH) and cool humid (26.5 ± 1.96°C, 64.5 ± 9.81% RH) seasons**

Initial food quantity (G)	None	Half	Equal	Mean
		Hot dry		
40	13.275 (40G)**	14.508 (60G)	15.997 (80G)	14.593
20	12.433 (20G)	11.607 (30G)	18.673 (40G)	14.238
10	23.933 (10G)	18.423 (15G)	26.642 (20G)	22.999
5	20.767 (5G)	18.478 (7.5G)	15.933 (10G)	18.393
Mean	17.602	15.754	19.311	
		Cool humid		
40	19.685 (40G)	22.943 (60G)	18.007 (80G)	20.212
20	17.967 (20G)	18.473 (30G)	20.172 (40G)	18.871
10	27.550 (10G)	22.000 (15G)	32.117 (20G)	27.222
5	29.367 (5G)	21.932 (7.5G)	19.575 (10G)	23.624
Mean	23.642	21.337	22.467	

Hot dry season: SE± = 1.33, LSD = Ns (Food quantity added); SE± = 1.54, LSD = 4.3514 (Initial food quantity); SE± = 2.66, LSD = Ns (Interaction).
Cool humid season: SE± = 1.75, LSD = Ns (Food quantity added); SE± = 2.02, LSD = 5.7304 (Initial food quantity); SE± = 3.50, LSD = Ns (Interaction).
* Counts taken at 80 DAI
** Quantity of food

Table IV. Effects of food supplementation on available quantity of food (g)/*T. castaneum during the hot dry (31.1 ± 3.14°C, 18.9 ± 11.1% RH) and cool humid (26.5 ± 1.96°C, 64.5 ± 9.81% RH) seasons**

Initial food quantity (G)	Food quantity(g)/(F_2) — Food quantity added to the initial after 40 days of infestation, i.e. after emergence of F_1			
	None	Half	Equal	Mean
		Hot dry		
40	0.0837 (40G)	0.0785 (60G)	0.0673 (80G)	0.0765
20	0.0917 (20G)	0.0963 (30G)	0.0635 (40G)	0.0838
10	0.0475 (10G)	0.0610 (15G)	0.0380 (20G)	0.0488
5	0.0615 (5G)	0.0572 (7.5G)	0.0822 (10G)	0.0669
Mean	0.0711	0.0733	0.0628	
		Cool humid		
40	0.0560 (40G)	0.0522 (60G)	0.0615 (80G)	0.0566
20	0.0600 (20G)	0.0603 (30G)	0.0550 (40G)	0.0584
10	0.0420 (10G)	0.0510 (15G)	0.0317 (20G)	0.0416
5	0.0427 (5G)	0.0525 (7.5G)	0.0642 (10G)	0.0531
Mean	0.0502	0.0540	0.0531	

Hot dry season: SE± = 0.007, LSD = Ns (Food quantity added); SE± = 0.008, LSD = 0.0221 (Initial food quantity); SE± = 0.0135, LSD = Ns (Interaction).
Cool humid season: SE± = 0.004, LSD = Ns (Food quantity added); SE± = 0.005, LSD = Ns (Initial food quantity); SE± = 0.009, LSD = Ns (Interaction).
* Count at 80 DAI
** Quantity of food

half and 10G food supplemented by the same quantity. Lowest insect population was recorded on 20G food that was not supplemented, 10G food supplemented by half or not supplemented and 5G food.

There was a negative relationship between population of *T. castaneum* at 40 DAI and that at 80 DAI (Fig. 1). Also, adults of *T. castaneum* increased at a faster rate than larvae

Fig. 1. Relationship between F_1-population of *T. castaneum* at 40 DAI and F_2 population at 80 DAI

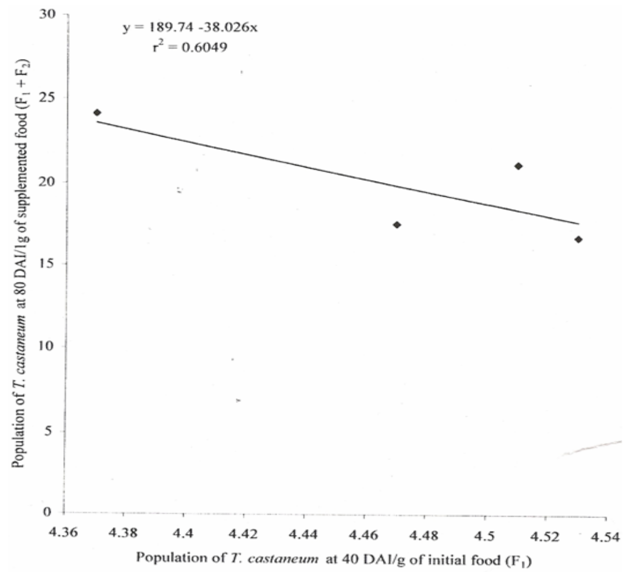
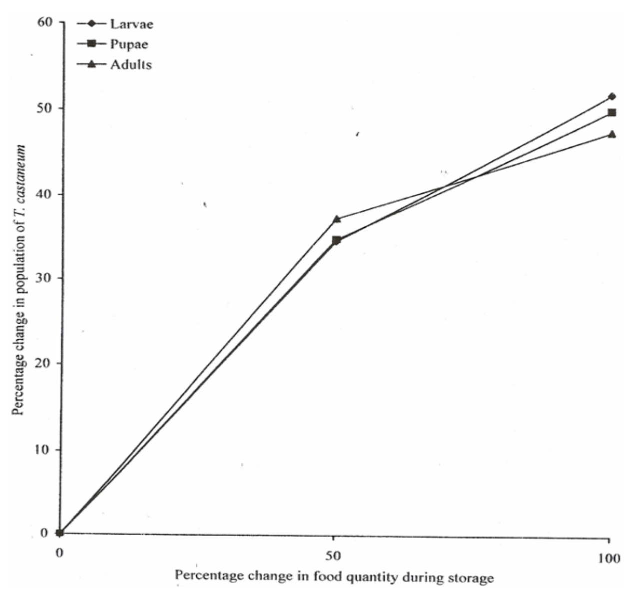
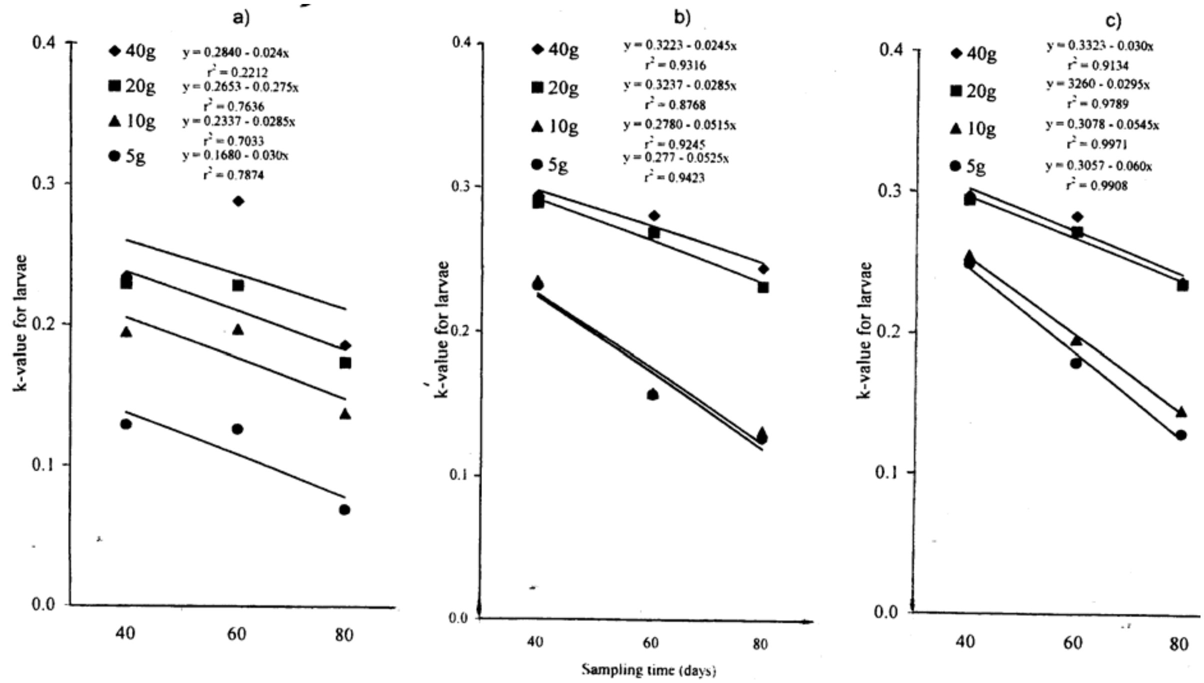


Fig. 2. Relation ship between percentage in population of different life stages of *T. castaneum* and percentage change in flour quality supplied to *T. castaneum*



or pupae when food was increased by half (50%) of the initial quantity. However, doubling (100% increase) the food supply caused decrease in adult population to below that of larvae and pupae; the percentage increase in the population of larvae was higher than that of pupae (Fig. 2). Mean number of *T. castaneum* that developed in 1 G flour was significantly higher in the initial quantity of 10 G than 40 or 20 G flour (Table III). Similarly, more food was available for the insect from the initial quantity of 10 G than 40 or 20 G flour (Table IV). The relationship between

Fig. 3. Relationship between mortality (k-value) for *T. casteneum* and sampling time- a) none (0%) added flour; b) half (50%) quantity of flour added and c) equal (100%) quantity of lour added to the initial flour during the hot dry and cool humid seasons



mortality of *T. castaneum* and length of flour storage (sampling time) was negative for both initial and supplemented diets (Fig. 3).

DISCUSSION

During both seasons, the population of *T. castaneum* in the initial quantity of 40 G flour or when supplemented was significantly lower 40 DAI and significantly higher 80 DAI than 10 or 5 G flour, suggesting that higher quantity of food may not necessarily support higher initial development in *T. castaneum*. It is not known whether fine texture of flour adversely affects the potential of *T. castaneum* to achieve high initial fecundity. Most adults were observed to be on the surface of the flour. Campbell and Runnion (2003) reported that large quantities of flour are tightly packed. It was possible that the fine texture of flour and the larger quantity of 40 G flour may have predisposed the flour to be tightly packed and consequently restricted initial accessibility to *T. castaneum* to few niches for oviposition more in 40 G than 10 or 5 G flour. In addition, *T. castaneum* secretes aggregation pheromone (Arnaud *et al*., 2002). The net effect of these is that in highly packed flour intraspecific contact among coexisting individuals may be aggravated in the few accessible niches.

Egg cannibalism in *T. castaneum* can arise as a result of high density (Yoshida, 1974) and larval cannibalism can be quite intense (Ghent, 1966). Intense cannibalism may have been partly responsible for low population of F_1-progeny of *T. castaneum* in initial quantity of 40 G flour 40 DAI; density dependent mortality, dispersal and/or reduced fecundity are common in *T. castaneum* (Berryman, 2004; White, 2004). Also, the relationship between k-value and available flour for each *T. castaneum* was positive suggesting that mortality in *T. castaneum* increased with available food (flour) regardless of the variation (addition) in the quantity of the flour. The implication is that the higher population of *T. castaneum* in added flour of the same initial quantity (40 G) 80 DAI may be accounted for low mortality from reduced cannibalism, which has the property of slowing down population growth when density is high and allowing the population to speed up when density is low (Gotelli, 1998; Park *el al*., 1965).

In contrast, small quantities of 10 G and 5 G flour may be loosely packed in the container and this is likely to reduce intraspecific contact among coexisting individuals in the flour. In addition, sparse or depleted resources are patchily distributed (Bell *et al*., 1996) and *T. castaneum* has adaptation for exploiting patchy resources (Campbell & Runnion, 2003). It is not known whether this behavior, together with reduced intraspecific contact facilitated the increase in the population of F_1-progeny of *T. castaneum* in 10 or 5 G flour 40 DAI. On the other hand, higher population density in small quantities of flour might have intensified intraspecific predation among *T. castaneum* and this may have partly accounted for low population of *T. castaneum* in the supplemented flour of the same initial quantity of 10 or 5 G 80 DAI. The negative relationship between the population of *T. castaneum* 40 DAI and 80 DAI indicates that increases in the population of *T. castaneum* 40 DAI were associated with reverses in increases in the population of *T. castaneum* 80 DAI.

The results have several important implications for handling of flour in this region. Firstly, small scale or domestic handling of flour may encourage high infestation of flour by *T. castaneum* in short term storage and under fixed conditions may result into density dependent dispersal of the beetles. Secondly, dispersal of *T. castaneum* may be accompanied by cross-infestation of major commercial stores and in the long-run may raise the cost of management. Thirdly, small scale holding is an important point of emphasis for the control of *T. castaneum*. It has been suggested that careful sanitation is the best method of controlling *T. castaneum* (Bennet, 2000). This is important as sanitation can be made at domestic level. Moreover, the negative relationship between k-value and storage time obtained in this study suggests that cannibalism (or dispersal as the case may be) may decrease with longer storage, the consequence of which is build-up in the population of *T. castaneum*. This may happen with higher volumes of flour in storage. It is known that cannibalism in *T. castaneum* can cause chaotic behavior or aperiodic cycling of the different life stages of *T. castaneum* and destablise the population (Bell *et al.*, 1996): higher percentage of adult population over those of larva and pupa accompanied 50% food supplementation. Conversely, 100% food supplementation supported lower population of the adult than larva or pupa. The implication is that higher losses of infested flour may accompany surges in population of *T. castaneum*, especially under tropical storage conditions, where population monitoring is hardly important or undertaken as routine warehouse exercise. In contrast, population monitoring and forecasting of upsurges are important tools for successful pest management (Norton, 1982; Kumar, 1984).

Acknowledgement. The authors thank Professor W.S. Richards, Department of Biological Science, University of Maiduguri for generous provision of reference materials and Dr. Z.G.S. Turaki of the Lake Chad Research Institute, Maiduguri (Nigeria) for data analysis.

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(Received 25 February 2008; Accepted 23 June 2008)