Studies on the Biology of the Red-flour beetle *Tribolium castaneum* Herbst., (Coleoptera: Tenebrionidae) in different cereal flours

By

Adil Shareif Mohamed Khair

B.Sc.(Agric.) Hons. University of Khartoum (1982)

A thesis
Submitted in partial fulfillment of the requirements for the degree of M.Sc.(Agric.)

Supervisor: Prof. ELSAYED EL BASHEIR MOHAMED

Faculty of Agriculture

University of Khartoum

November 2002

DEDICATION

To the spirits of my parents
Haja – Khitma

And

Haj – Shareif

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I am greatly indebted to professor ELSAYED EL BASHIR MOHAMED, for his supervision, advice and continuous helpful guidance. It was, solely, through his invaluable advice and encouragement that I was able to present this thesis.

It is my obligation to extend my appreciation to the staff of the Institute of the Promotion of Animal Exports (Faculty of Vetrinary Medicine, University of Khartoum) for availing their laboratory services.

Also thanks are extended to Ustaz Gammaa A. Mohamed, (Biochemistry Laboratory of the Faculty of Agric., University of Khartoum) for his assistance with the chemical analysis.

Many thanks are due to Dr. Tag ELSir B. Laoata, for his assistance in the statistical analysis of the data and in some graphical representations.

Special thanks are conveyed to engineer Mutwakil Daffalla and Miss. Ekhlas Yasien for typing the thesis.

Finally, I am especially indebted to my wife, for her support and encouragement, which were major privileges during the entire course of the work.

ABSTRACT

Experiments were conducted at the Entomology Laboratory of the Faculty of Agriculture, University of Khartoum, Shambat, Sudan. Chemical analysis of the four cereal flours was carried out at the Biochemistry Laboratory of the Faculty of Agriculture, University of Khartoum. The objectives were to study the biology of the red flour beetle *Tribolium castaneum* Herbts., when reared on flours of sorghum, wheat, millet and rice and to investigate the relative susceptibility of these four cereal flours to infestation by this pest..

Morphological studies of *T. castaneum* on sorghum flour were carried out and the egg, different larval instars, pupae and adults were described. The average length of the fully grown larva, pupa and adult were 5.84, 4.00 and 4.52mm, respectively.

Life-cycle studies of *T. castaneum* at uncontrolled laboratory conditions, have shown that, egg incubation, larval, pupal and total developmental period in sorghum flour were significantly different. The total development period varied considerably according to the prevailing environmental conditions particularly the temperature. Thus the shortest durations were recorded in June (higher temp.) and the longest in September and October (lower temp.).

The biology of *T. castaneum* was studied on wheat, millet, sorghum and rice flours in uncontrolled laboratory conditions.

The flour type (food) had a significant effect on the total developomental duration of the beetle. Millet was the most favourable and rice was the least favourable for the development of the different stages of the beetle. Also food had a significant effect on the body mean weight of the different stages of the insect. The mean weight of larva, pupa and adult were less for insects reared on rice flour than for those reared on wheat flour. The ratio of males to females, sex ratio of *T. castaneum* was close to unity on sorghum flour, greater than unity on both millet and wheat flours, but less than unity on rice flour and with predominance of males.

Studies have shown that, on the basis of total progeny of *T. castaneum* produced and the percentage of weight loss in the infested cereal flours, none of the cereal flours was completely resistant to infestation. However, response to infestation varied significantly from one ceral flour to the other. Significant differences in percentage weight loss in each month over a period of three months were recorded in flours of wheat, millet, sorghum and rice. Considering weight loss as the main indication of susceptibility, rice appeared to be the least susceptible (lowest total percentage of weight loss), while wheat and millet flours were the most susceptible (highest total percentage of weight losses). Insect population increased significantly on wheat and millet flours (most suitable), when compared to that on the flour of the other two cereals, particularly rice flour (least suitable).

For the chemical composition of the different flours, the differences between their moisture content were not significant. Differences in protein content were highly significant, however, protein contents of wheat and millet were the same and significantly higher than that of sorghum and rice. Also ash and oil contents among the four flours were significantly different. The differences between carbohydrate contents of the flours were significant with rice showing the highest level and millet the lowest. Lower amounts of ash, oil and proteins were found in rice flour than in the other three flours, this may explain why *T. castaneum* was not able to develop and multiply faster on rice flour.

Generally, the study showed the ability of *T. castaneum* to survive and complete development in all four types of the cereal flours.

ملخص الأطروحة

دراسة بيولوجية سوسة الدقيق الحمراء

Red flour beetle (*Tribolium castaneum* Herbst.)

في أنواع مختلفة من دقيق الغلال

أجريت هذه التجارب بمعمل الحشرات – كلية الزراعة – جامعة الخرطوم شمبات – السودان. وتم التحليل الكيميائي لدقيق الغلال الاربعة بمعمل الكيمياء الحيوية بكلية الزراعة – جامعة الخرطوم. هدفت الدراسة إلى معرفة بيولوجية الحشرة عند تربيتها على دقيق الذرة الرفيعة ، القمح ، الدخن والأرز. وكذلك لدراسة مدى القابلية للإصابة بهذه الآفة في دقيق هذه الغلال.

تمت دراسة شكل هذه الخنفساء عند تربيتها على دقيق الذرة الرفيعة وتم وصف اطوارها المختلفة (البيض ، اليرقة ، الشرنقة والحشرة الكاملة) ووجد ان متوسط طول الجسم لليرقة تامة النمو ، الشرنقة والحشرة الكاملة هي 5.84 ، 4.00 و4.52 ملم بالترتيب.

دراسة اطوار النمو لسوسة الدقيق الحمراء تحت ظروف معملية (غير متحكم فيها) اوضحت ان فترة حضانة البيض وفترة نمو اليرقة والشرنقة تختلف اختلافا معنويا عند التربية على دقيق الذرة الرفيعة ، كما ان فترة النمو الكلي للحشرة تختلف اختلافا ملحوظا حسب الظروف البيئية المحيطة خاصة درجات

الحرارة. وبالتالي فان اقل فترة نمو سجلت في شهر يونيو (أعلى درجة حرارة) وأطول فترة نمو سجلت في شهري سبتمبر واكتوبر (أقل درجة حرارة).

أيضا تمت دراسة بيولوجية هذه الحشرة عند تربيتها على دقيق القمح ، الذرة الرفيعة، الدخن والارز تحت ظروف معملية (غير متحكم فيها). وأظهرت الدراسة أن نوع الدقيق (الغذاء) له تأثير معنوي على فترة النمو الكلي لهذه الحشرة. دقيق الدخن كان الاكثر ملائمة لنمو وتكاثر الاطوار المختلفة لهذه الحشرة بينما كان دقيق الارز هو الاقل ملائمة للنمو والتكاثر. أيضا للغذاء تاثير معنوي على متوسط وزن الجسم للاطوار المختلفة للحشرة. توصلت الدراسة إلى أن الحشرات التي تمت تربيتها بدقيق الأرز أقل وزناً عن تلك التي تمت تربيتها بدقيق القمح. أظهرت نتائج الدراسة أن نسبة الذكور للإناث (النسبة الجنسية) لهذه الحشرة في دقيق الذرة الرفيعة هي تقريباً بنسبة واحد إلى واحد ، بينما في دقيق القمح والدخن تزيد نسبة الإناث للذكور وفي دقيق الأرز تفوق نسبة الذكور الإناث.

أوضحت الدراسة انه وعلى اساس التكاثر العددي للحشرة والنسبة المئوية للنقصان في وزن الدقيق المصاب ، لا يوجد دقيق بين هذه الانواع - تحت الدراسة – له المقدرة على المقاومة الكلية ولكن مدى القابلية للاصابة بهذه الحشرة يختلف من دقيق لاخر. وعند مقارنة النسبة المئوية للنقصان في الوزن في كل

شهر لفترة ثلاثة شهور ، سجلت الدراسة اختلافات معنوية في انواع الدقيق الاربعة. وبأخذ النقصان في الوزن كمؤشر رئيسي لقياس مدى القابلية للإصابة بهذه الحشرة ، أظهرت الدراسة أن الأرز يعتبر الاقل اصابة (الأقل نقصاناً في الوزن) بينما القمح والدخن هما الأكثر قابلية للإصابة (الأكثر نقصاناً في الوزن).
أما التكاثر العددي للحشرة فقد ازداد معنويا في دقيـق القمـح والـدخن (الأكثـر ملائمة) عند مقارنته بالنوعين الآخرين من الدقيق وخاصة دقيـق الأرز (الأقـل ملائمة).

أوضحت نتائج التحليل الكيميائي لأنواع الدقيق المختلفة انه لا توجد اختلافات معنوية في نسبة الرطوبة بينها. نسب البروتينات تختلف اختلافا معنويا عاليا ، ولكن نسبة البروتينات متساوية في القمح والدخن وهي اعلى من نسبة بروتينات الذرة الرفيعة والارز. نسب الرماد والزيوت ايضا تختلف اختلافا معنويا كما ان نسب المواد الكربوهيدراتية تختلف من دقيق لاخر حيث وجدت اعلى نسبة في دقيق الارز واقلها في دقيق الدخن. أقل نسبة من البروتينات ، الرماد والزيوت وجدت في دقيق الارز مقارنة بالانواع الثلاثة الاخرى ، وهذا ربما يفسر عدم مقدرة الحشرة على النمو والتكاثر السريع في دقيق الارز.

عموما ، من خلال هذه النتائج فان الدراسة أوضحت مقدرة الحشرة على البقاء والنمو في جميع أصناف دقيق الغلال الأربعة.

CHAPTER ONE
INTRODUCTION

Grains can be infested by pests at all stages following their harvest until they are processed and consumed. The most commonly attacked products are those of food grains and the least are the dried fruits (William, 1991). Cereals form the staple diet for humans in many countries and constitute a major component of animal feed.

Prior to consumption or marketing, surplus cereal grains are usually stored for variable periods under different conditions. Storage is a post-harvest practice which when properly managed can help in alleviating problems of food shortage. Recognition of this practice is widespread in developed countries but not in the developing countries. Agricultural centres in sub – tropical and tropical countries are fighting hard to increase production, but they are still not fully aware of the quantity of produce lost between harvest and consumption.

Improvement in food grain storage can help maximize benefits from the existing agricultural production. It is essential therefore to have good storage structures, so as to minimize quantitative and qualitative losses, overcome scarcity, and enhance the producers' financial benefits (Adesuyi, 1993).

Insects are considered to be the most important pests of stored grains throughout the world. In the Sudan most of the species of stored - product pests occur throughout the more humid areas, in these areas *Sitophillus oryzae* (L.), *Sitotroga cerealella* (Olivier) and *Corcyra cephalonica* (Staint) are more common. In the dry northern Sudan two primary pests dominate, namely, *Trogoderma granarium* (Everts) and

Rhizopertha dominica (F.), but *Trogoderma granarium* appears to be the most important.

Most important of the secondary pests are *Tribolium* spp. They are generally distributed throughout the Sudan but are more plentiful in areas of higher humidity (Darling, 1959). *Tribolium castaneum* Herbst, (the red - flour beetle) and *Tribolium confusum* Jacqueline duval, (the confused flour beetle) occur on a wide variety of stored processed grains and are major pests at flour mills.

In the Sudan, *T. castaneum* is more common than *T. confusum* (Khalil1970). Both *Tribolium* spp are frequently referred to as secondary pests since they are unable to feed or attack sound grains, but cause considerable damage to grains previously attacked by internal feeders (primary pests) or are mechanically damaged.

Insects are controlled principally by the use of insecticides (FAO, 1983), but several commonly used chemicals are no longer recommended for use on stored grains because of their potential health hazards to humans hence, there is need for safer and effective methods of insect control.

Insufficient work has been done in this country to study the storage problems which include storage methods, loss assessment, varietal susceptibility of grains to stored product pests, biology and ecology of pests. The present work is an attempt to investigate some of these aspects. In particular it focuses on the duration of development and food suitability for *T. castaneum* when exposed to flours of sorghum, wheat, millet and rice under uncontrolled laboratory conditions.

The objectives of the present study were:

1- To determine the effect of food on the duration of development of *T. castaneum*
2- To investigate the relative susceptibility of four cereal flours to infestation by *T. castaneum*.

CHAPTER TWO

LITERATURE REVIEW

2.1. Importance of cereal grains

Cereals in the Sudan include sorghum, millet, wheat, maize, telebon and rice. Among these grains only the surplus of sorghum and millet are exported while wheat and rice are imported, however there is a good potential for export of surplus maize in the future (Mahmoud, 2001).

Cereal grains are the main source of food for humans in many countries and constitute about 71% of the staple diets of local populations in Africa (Hall, 1970). Sorghum is the fifth most important world cereal crop (More *et al*.1992) and is one of the major food crops grown in the tropics and subtropics (Hall, 1970).

Sorghum is the staple food in many African countries including the Sudan (Shazali and Ahmed, 1998). It is the staple food in most regions of this country. It contains a reasonable amount of proteins, ash, carbohydrates, oils and fibre (Drich and Pran, 1987).

In the Sudan, sorghum is widely grown in areas of sufficient rainfall or under irrigation and is the most popular food grain (Elhag, 1992, Shazali *et al*. 1996). In season (99/2000), it is estimated that sorghum occupied 61.4% of the area allotted to cereals and accounted for 76.7% of the total grain production (Ministry of Agriculture, 2001).

In the Sudan, pearl millet, locally known as dukhun, is the third most important staple food crop after sorghum and wheat, with annual production of 800.000 metric tons and of immensely greater nutritional value in the diets of poor people in western Sudan (Abdalla *et al*., 1997).

Records of the Sudan Agricultural Bank show that the quantity of grains stored for more than six months starting January 2002 is about 11482 .107 tons.

2.2. Grain Losses

Adams (1977) defined loss as decrease in weight of grain over a period of time possibly due to different factors. Post -harvest losses could be of quantitative or qualitative nature, and can generally be reflected in several ways such as weight loss, nutritional and monetary loss (Hall 1970, FAO 1983 and Pederson 1992).

In the assessment of food losses, reduction in weight is one of the most frequently used criterion. Losses in temperate regions of the world due to insect damage can be expected to be lower than in the tropics and subtropics. The tropics and subtropics provide optimum conditions for pest multiplication, and losses tend to increase (Shazali 1987, Harein and Davis1992).

The word quality as applied to food materials refers to those attributes of food, which make it agreeable to persons who eat them. It involves colour, flavour, texture, nutritive value and freedom from harmful substances such as pesticides residues, biochemical changes and contamination by insect body fragments or excreta (Shazali1987, and Pederson 1992)

2.3. Factors affecting losses of stored grains

Damage to stored grains due to insect infestation during storage is influenced by several factors which include mainly, the climatic conditions, the botanical, physical, chemical, other features of the grains, the method of storage adopted and the degree of efficiency of the control measures applied (Darling, 1959 and Saad 1978).

According to Hall (1970) and Shazali (1987) these factors are grouped into physical (temperature and moisture), biological (insects, micro-organisms, rats and birds), engineering (design of storage structure and handling equipment), and socio-economic (living and educational standards).

2.3.1. Physical factors:

Damage to stored grains is largely dependant on the moisture content of the grains and on temperature (Brooker *et al*., 1981, and Bailey 1992). The moisture content of the grains and the atmospheric relative humidity both have direct effect on the degree of the susceptibility of stored grains to attack by insects. Moisture is the most important factor inducing fungal growth as it leads to the deterioration of stored grain within a very short time (Christensen *et al*. 1969, Pomeranz 1992, and Iqbal *et al*. 1996).

Many researchers have reported that seasonal and daily fluctuations in temperature and solar radiation together with respiration heat of Arthropods and fungi affect the temperature pattern within stored grain mass and result in moisture transfer form warm to cool areas. Pockets of high moisture within the stored commodities enhance mould growth although grains may be stored at safe moisture levels (Sinha and Wallace 1977, Uiso *et al*. 1990). Moisture and temperature increases within stored grains are good indicators of the presence of Arthropods and fungi (FAO 1983, Bailey 1992 and Basumia *et al*., 1996).

2.3.2 Biological factors:

The biological agents commonly responsible for the deterioration of stored grain are insects, fungi, mites, rodents and birds (Pomeranze 1992). Rodents and birds cause extensive damage to both standing crops and stored products but damage to stored grains is greatest (Hall 1970). Mites cause damage to grains in temperate regions, but do not constitute danger to stored grains in the tropics and sub tropics (Brooker *et a*l. 1981, Bell and Armitage 1992).

Stored grain insects are usually members of the orders Coleoptera (weevils and beetles) and Lepidoptera (moths) (Pederson 1992).

Insects cause direct damage as a result of consumption of grain kernels thus affecting viability and nutritive value of the seeds. They may also change the chemical composition of the infested commodity and contaminate it with their broken appendages and metabolic by- products.

The indirect damage includes heating as a result of metabolic processes, distribution of microorganisms in grain masses by transportation of mould spores and creation of favourable conditions for mould growth (FAO 1983 and Pederson 1992). In addition allergies are also widespread hazards associated with insect infestation of food materials (Phillips and Burkholder 1985).

Hall (1970) reported that grain size, physical properties (e.g hardness) composition and nutritive value also influence the development of stored grain insects.

2.4. Losses of Stored Products Caused by Insects in Sudan.

Insects are the main pests, which cause damage to stored grains all over the Sudan (Darling 1959, Saad and Guddoura1982; Guddoura and Medani 1987).

The percentage of losses due to insects in ware houses may exceed 20% in case of long- term storage for (more than 6 months) in ground nut (Khalil 1975; and sorghum (Elagib, 19 87), but it is less in pits and silos in sorghum (ElKhidir 1982).

Generally storage losses due to insect infestation in Sudan increase from north to south due to the high relative humidity in the southern regions, where storage of food crops for more than six months is difficult (Darling 1959, Itto 1987).

The dry and warm conditions in northern Sudan are normally less conducive to insect attack, but *T.granarium* is commonly found to infest stored grains in this region. In spite of its limited reproductive capacity, the khapra beetle is dominant due to the fact that it tolerates dry and hot conditions.

According to Darling (1959), high losses due to store pests are characteristic of the Red Sea coastal region where the relative humidity is high (annual average about 55%). This, coupled with high temperatures, encourages insect attack. Saad (1978) added that as Port Sudan accommodates the largest facilities for storage of grains in the Sudan, insect pests cause considerable losses.

In central Sudan, losses of stored grains are very high because this is the most productive area in the country and has always had large surplus in excess of the needs of its inhabitants (Darling 1959, Saad 1978). The grain surplus is usually stored within the region for several months or even years after harvest. The daily mean atmospheric relative humidity in this area during the rainy season is about 75% while in the dry season it is less than 30% (Darling1959). Thus insect population is high during the rainy season and low in the dry season.

Losses of stored grains in southern Sudan amount to as high as 20% by weight (Darling, 1959, Saad, 1978). This is because the climatic conditions in that region, particularly the high relative humidity, render the grain more susceptible to insect attack and at the same time favour the rapid development and multiplication of insects.

2.5. Main stored grain pests in Sudan

The khapra beetle, *Trogoderma granarium* Everts, is the most destructive insect in the Sudan, particularly in the semi arid hot dry northern part (Darling 1959). In the Red Sea coastal area, particularly at Port Sudan, severe infestations by many insects especially *Trogoderma granarium* and *Tribolium castaneum* Herbst were reported to occur throughout the year (Saad, 1978). *Rhizopertha dominica* is also an important grain pest particularly in central Sudan where most of the sorghum is produced and stored. *Sitophilus oryzae* L., which is not found in northern Sudan, is of great importance in the southern parts of central Sudan probably due to the prevailing high humidity during the rainy season (Seif Elnasr 1992).

In the Sudan, *T. castaneum* is more common than *T. confusum* (Khalil, 1970), perhaps an indication that the latter species is less tolerant to hot conditions (Good, 1933 and Seif Elnasr 1992). Other important insects include the Angoumois grain moth *Sitotroga cerealella* and the rice moth, *Corcyra cephalonica.* Neither *Sitophilus oryzae* nor *Sitotroga cerealella* were found in underground pits (matmoras) (Itto- 1987; Shazali 1987).

S. cerealella is usually important in out – door or open storage, particularly sorghum stored on the heads or in loosely stacked sacks, because of its inability to penetrate deep into bulk stored grains. The population of all stored grain insects usually increases steadily during the rainy season, (June – October) with maximum numbers at the end of the season. The duration of storage also affects the relative abundance of insects as well as their succession (Shazali 1982).

2.6. Effect of temperature and humidity on stored product insect pests:

The development of different stages of *Trogoderma granarium* and *T. castaneum* was accelerated by higher temperatures. The optimum was found to be 35°C (Nigam1966).

Yinon and Shalov (1970) found that, the preferred zones for *Trogoderma granarium* were 28°C, to 33°C, 25°C to 34°C, for *T. catanum*, 22°C to 26°C for *Oryzaephilus* sp., 20°C to 24°C for *Sitophilus oryzae*, 23°C to 28°C, for *Tenebriodes mauritancust* and 22°C to 28°C for *Rhizopertha dominica.* Karan *et al.* (1973) showed that the optimum temperature and relative humidity for *Sitophilus oryzae* were 30°C and 75% RH.

2.7. Varietal susceptibility of grains to insect infestation

Some varieties of sorghum, millet and wheat were found to be less suitable than others for insect development (Darling 1959, Shazali 1982, Mustafa 1983 Seif Elnasr and Mill 1985 and ELHag 1992). The sorghum varities of Mugud and Safra were relatively susceptible while Wad Akar and Fatarita were considered resistant (Darling, 1959).

Shazali (1987) reported that Dabar was the less susceptible than safra and ELHag (1992) reported that Dabar and Wad Fahal were less damaged by storage insects than Wad Akar and Hageen. However, none of these varieties was completely resistant. Samuel and Chetterji (1953) investigated sorghum resistance to attack by some species of stored product insects, including *Rhizopertha dominica, Sitophilus oryzae* and *T.*

castaneum. They found that unthreshed varieties were almost totally resistant to all insects except *R. dominica* which was able to attack all varieties. Russell (1966) reported that the life span of *Sitophilus oryzae* decreased with the increase in the hardness of the sorghum grain. He observed that females prefered large seeds for oviposition in comparison to small sized seeds. Doraiswamy *et al* (1976) suggested that seed colour, seed weight and size had no association with the relative incidence of *Sitophilus oryzae.* They found that seed hardness had a negative correlation with susceptibility of sorghum grain to insect attack.

In Sudan, Shazali (1977) tested the susceptibility of sorghum to *T. castaneum* attack. He concluded that *T. castaneum* was able to feed on sound grain sorghum (Um Benein variety), apparently on the surface. He also found that feeding and reproduction increased with an increase in the amount of broken grains.

Similar studies on resistance had been conducted on wheat by Bains, (1971) who found that susceptibility of wheat seeds to *Rhizopertha dominica* was associated with the softness of the germ portion of the grain and possibly with an increase in the carbohydrate content. Dalel and Gupta (1974) and Phadka and Bhatia (1974) studied the relative resistance of wheat varieties to *Sitophilus oryzae* and *Rhizopertha dominica* in India and showed that none of the varieties tested in the laboratory were immune to the two species, although there were indications that high protein content and moisture enhanced susceptibility while hardness of the grain was positively correlated with resistance. They also found that temperature played a significant role because higher grain infestation occurred when the varieties were incubated at the optimum temperatures of 27.5°C, for *Sitophilus oryzae* and 34.0°C, for *Rhizoperha dominica*.

2.8. *Tribolium castaneum* Herbst., (the red flour beetle)

2.8.1. Description and identification

Tribolium castaneum Herbst, commonly known as the red flour beetle, belongs to the family Tenebrionidae, order Coleoptera. The flour beetles are known by a number of common names. Grain millers refer to species of *Tribolium* and other closely related beetles of similar appearance as (flour beetles), (flour weevils), (red weevils), or (bran bugs). The accepted common name of *T. castaneum* is the rust red flour beetle (Good 1936).

The two species *T. castaneum* Herbst., the red flour beetle and *T. confusum* Duv., the confused flour beetle were both recorded in Sudan (Khalil, 1970). They are so similar in size, shape of body and habits that they are often confused with one another on casual examination.

The distinguishing characters are very similar and a definite distinction between the two species is possible only on close microscopic examination.

T. castaneum adult is 3 to 4 mm in length, parallel sided and reddish brown in colour. The antennae are composed of eleven segments with the last three comprising the club. The compound eyes are partly divided horizontally by a back ward projection of the head (Anon. 1986).

In *T. castaneum*, the width of the compound eyes is approximately equal to the distance separating them on the underside of the head.

In *T. confusum* the eyes viewed from below, appear small, the width of each being approximately only one third of the distance separating the two eyes. This character can be used for the identification of living and dead specimens (Good 1933). Another character commonly used for differentiating between *T. castaneum* and *T. confusum* is the abrupt enlargement of the three distal segments of the antenna of *T.castaneum* (club-shaped antenna) as compared to the gradual enlargement of the antenna in *T. confusum*.

In *T. castaneum* the wings are functional while in *T. confusum* they are not (Good 1933). *T. confusum* averages 3.47 mm in length and 1.07mm in width, whereas *T. castaneum* averages 3.32 mm in length and 1.03mm in width (Good 1933). Larvae of the two species closely resemble each other, but larvae of *T. confusum* have more and longer setae than do those of *T. castaneum* (Frank 1967). *T. confusum* closely resembles *T. castaneum* in the pupal stage as well as in the adult stage (Frank 1960).

At the pupal stage sexing can be done easily on the basis of the external characters. The appearance of the ventral surface of the terminal abdominal segment of the pupa differs greatly in the males and females. The chief characteristic feature of this segment in the male is a flat disc-like depression whereas in the female they are two cone –like appendages, similar in appearance to the urogomphi, but much shorter and relatively thicker (Good, 1936). The pupae are pale in colour and immobile, except for the ability to flex the body between the thorax and abdomen rendering the sexing of the living pupa more convenient.

2.8.2. Distribution and host range:

T. confusum and *T. castaneum* are cosmopolitan, occurring all over the world wherever stored cereal products are to be found. As they live inside buildings and may easily be carried from place to place in small quantities of foodstuffs, these beetles are likely to be recorded from practically any part of the world. *T. castaneum* is essentially an insect of warm climates, (Good, 1936).

The flour beetles are known to attack such a wide variety of foods that they can be said to be practically omnivorous. They have been found feeding on over 100 different foodstuffs. The list comprises mainly grains and seeds of various kinds, flour, and other cereal products, but it also includes animal matter, wood, dried vegetables, fruits and spices (Good, 1936). Grain flour is the material principally infested by *Tribolium*. spp. practically any kind of flour may be infested, and whole-wheat flour seems especially liable to attack.

T. castaneum cannot feed on intact, undamaged grain because its mandibles are not strong enough to chew through the tough outer coating. Practically all lots of grain, however, contain a certain percentage of broken kernels, so these beetles may be found infesting almost every known kind of grain (Good, 1936).

2.8.3 Life history

2.8.3.1. Mating, pre- oviposition period and oviposition rate.

Mating usually begins within a day or two after adult emergence and probably continues at frequent intervals throughout the life span of the insect. Good (1936) stated that the pre-oviposition period of *Tribolium* species might range from four to an indefinite number of days according to temperature. He also stated that adults emerging during winter when kept under room temperature did not lay eggs until the approach of warm weather. Khalifa and Badawy (1955 a) reported that the shortest pre-oviposition period of *T. castaneum* was 4.9 days and the longest was 12.92 days at the beginning of winter. Howe (1962) found that the shortest pre-oviposition period was 10 days, but it can extend to 15 days at 25°C and 70% R.H.

It is more difficult to have good estimates of the oviposition rate of most stored products insects than it is to measure their developmental period. The total number of eggs laid by a female of *T. castaneum* was 360.4 ± 27.9 eggs (Good 1936, Howe 1962).

It was also stated that the fecundity varied with food. Robert (1985) stated that each female of *T. castaneum* may deposit 400 to 500 eggs (average 450 eggs) depending on the food quality. In *T. castaneum* all unmated females laid fewer eggs than did the mated ones. The average number of eggs laid by mated and unmated females were 139.1 and 45.1 respectively (Khalifa and Badawy 1955a).

2.8.3.2 Incubation period and development

(a) Incubation period

Howe (1956) reported that eggs did not hatch at any humidity at 15°C or 17.5°C nor at 10% R. H at 40°C. Good (1936) reported total mortality of eggs under uncontrolled humidity at 35°C, and high mortality at 32°C. He also added that 30°C appeared to be close to the optimum incubation temperature. Good (1936) studied egg incubation period of the red flour beetle on different types of food including middlings, bran, whole wheat flour, corn meal, oat meal and white flour. He found that eggs kept at room temperature in April (temp. ranged from 18.5°C to 28.5°C and R.H ranged from 22 to 43%), required an average of 8.8 days to hatch. Eggs kept at room conditions in November (temp. ranged from 18 °C to 29 °C and R.H ranged from 27 to 47%), required 8 to 11 days with an average of 10 days. Khalifa and Badawy (1955b) stated that hatching did not occur below a temperature of 16°C.

(b) Larval development

The larvae are fairly active and live more or less concealed in the food in which they bury themselves if disturbed. They are a little less tolerant than eggs to extreme conditions (Howe 1962). Both Howe (1962) and Shazali (1982) concluded that 35°C and 70 % or higher %R.H. were optimum conditions for larval development.

Good (1936) reported that there was no fixed number of Laval instars, the number ranging from 5 to 11 or more, and that the usual number was 7 or 8. This variation is due to both external conditions, such as food, temperature and to inherent individual characteristics.

The larval period of *T. castaneum* ranged from 22 to 100 days depending on temperature and food. Good (1936) also stated that the optimum temperature for development approached 30°C. Khalifa and Badawy (1955b) reported a short larval period of 21.1 days in August (Mean temp. 30°C) and a much longer period of 40.5 days at the beginning of March (Mean temp. 15° – 17°C).

(c) Pupal development

The pupae when compared with the eggs and the larvae, seem to be less affected by external conditions. Good (1936), Khalifa and Badawy (1955 b) and Howe (1956) stated that the food of the larva had no obvious effect on the duration of the pupal stage, which was similar for larvae reared on wheat or groundnuts.

Khalifa and Badawy (1955b), who reared *T. castaneum* under uncontrolled conditions stated that the shortest pupal period was 5.8 days in July (Mean temp. 30°C) and the longest was 18.5 days in October (Mean temp. 20°C). Howe (1956) and Shazali (1982) reported that temperature had a significant effect on the pupal period and that the shortest pupal period of *T. castaneum* (4.5 days) was obtained at 35°C at which pupal mortality was low.

(d) Total development

In most insects the developmental period from egg to adult varies considerably according to the prevailing environmental conditions. This variability is mostly due to the varying rates of growth of the larval stage, which is greatly affected by environmental conditions. Khalifa and Badawy (1955 b) and Howe (1956) stated that the optimum conditions for rapid development of *T. castaneum* from oviposition to the emergence of the adult lies between 35°C and 37.5°C at 70 % R.H. They added that the development of one complete generation exceeds 30 days. Shazali (1982) reported that the conditions for the shortest development of *T. castaneum* are 35°C and 70 to 80 % R.H., and the longest development occurred at 25°C. It is clear that optimum conditions for *T. castaneum* result in a short life cycle, which contributes to a very high rate of increase. Such rate of increase could not be sustained for long and would be reduced by the effects of cannibalism, parasitism, predation, disease and competition for space and food.

T. castaneum is a colonizer species (Dawson, 1977). Successful dispersal is achieved by flying and is not only dependent upon the movement of infested food. In late afternoons many individuals fly from the surface of infested sacks. The beetles may also be observed flying from any storage facilities (Krishna murthy *et al*. 1987).

2.8.4. Nature of damage and economic importance

T. castaneum is frequently referred to as a secondary pest since it is unable to feed on or attack sound grains (Howe, 1956). It can survive on dry commodities and is particularly troublesome on milled cereals and animal feeds, but does not multiply rapidly on dry cereal grains, if these are undamaged and are free of grain fragments or other dockage (Anon 1986, Shazali and Smith 1990). *T. castaneum* prefers the embryo and may feed on whole kernels, if the moisture content is 12 % or higher. In addition to grains, *T. castaneum* attacks dried fruits (Khalil, 1970; Robert, 1985).

Shazali (1982) reported that *T. castaneum* is able to damage whole sorghum grains at high temperature and relative humidity, by feeding on microscopic lesions. Furthermore about 20 % of the kernels are usually damaged during harvesting and threshing processes in the Sudan. Thus, the so -called secondary pests might not need the help of primary pests.

Where these pests are present in large numbers the flour becomes greyish and discoloured and will mould more quickly than clean flour.
Some times the disagreeable, pungent odour given off by the insect scent glands (Quinones) is incorporated into the flour, giving it disgusting taste and odour (Good 1936, and Anon 1986).

2.8.5. Sex ratio

The sex ratio means the ratio of males in relation to females.
No records have been found in the literature about the effect of temperature and food on the sex ratio of *T. castaneum***.** Good (1936) found that of 800 individuals of *T. castaneum* reared on whole-wheat flour at 30°C, 52% were females and 48% were males. Two hundred

pupae of *T. castaneum* reared under similar conditions gave a sex ratio of 59% females and 41% males.

Howe (1956) reported that the sex ratio of *T. castaneum* was unity. M.c Gregor (1964) showed a sex ratio close to unity but with a slight predominance of males. Abdelsamad (1985) reported a sex ratio (on sorghum flour) of 1: 0.9, 1: 0.7, 1: 1.4 and 1: 1.4 at 25°C, 30°C, 35°C and fluctuating laboratory conditions respectively. Thus the ratio was close to unity at 25°C, greater than unity at 30°C, and less than unity both at 35°C, and at fluctuating laboratory conditions.

2.9. Storage methods

In countries where agriculture is predominantly at subsistence level, it is estimated that between 60 and 70 % of cereal grain production is retained at farm level (Boxall *et al.,* 1981) where it is stored using different traditional methods, for different periods of time.

The method of storage adopted has an influence on the storability of the grains. It has to give protection for the stored products against insects, rodents, rains and all other adverse conditions (Saad, 1978).

Different storage structures prevail in the Sudan, ranging from native mud bins "Swiba" underground pits, (matmora) grass huts (Guttia) and improved warehouses to modern concrete silos.

The underground pit, storage is the traditional method used especially in central Sudan which, according to Darling (1959) was an ideal method provided that grains did not remain in storage for more than five years.

Darling (1959) showed that the moisture content of grain sorghum did not change significantly except along the periphery of the pit, where absorption of water from moist air between soil particles was possible.

He added that seed germination and fatty acids of the grain were affected. Shazali *et al*. (1996) reported that the loss due to insect infestations was less in plastic lined matmoras (1.4%) than in above ground storage (3.7%) and the most dominant species were *T. castaneum, Rhizopertha dominica,* and *Cryptolestes sp*. However the losses due to mould were higher in traditional (butab) lining.
Boxall (1974) in Ethiopia, showed that the pits form reliable storage system that keeps minimum losses resulting from insects, moulds and rodents.

Grass huts are also common in the central rain lands. Bagged grain is stored above ground either in storage rooms or in the open. The type of stores common in northern Sudan are the bins “Swibas” made of sun dried clay where cultivators store their grain in bulk for short periods. The capacity of such stores is variable but seldom exceeds one ton (Darling, 1959).

Out- door or open storage in sacks arranged in pyramids or loose grain in bulk was practiced for sometime (Late 1940 s and 1950 s), in the dry northern part of the country (in Khartoum and Northern provinces). Platforms, slightly raised above ground level (Mastaba) were usually made, on which the sacks or the loose grains, were directly placed. Darling (1959) reported that (Mastaba) storage at Khartoum North was cheap and efficient for periods of one to two years. He found the heated grain becomes discoloured and unpalatable, and the reported wettings by rains, render the grain unfit for humans food. He found that *Trogoderma granarium* was the major pest causing losses. Khalifa (1960) described the attack of *Trogoderma granarium* as most serious in the bottom layers of stacked sorghum out – door, this was attributed to the direct reaction of sunlight as this insect is negatively phototropic. Hall (1963) stated that storage of grains in sacks or loose in bulk depends upon a number of local factors: type of produce, duration of storage, climate, transport system, cost and availability of labour and incidence of rodents and certain type of insect infestation.

Storage in general stores and in large – scale warehouses in the country is quite common. Khalil (1975) mentioned that in Port Sudan alone there were about 110 recognized warehouses of 100 x 50 x 8 meters. He added that all insects of stored products reported in Sudan are noticed there, with *Trogoderma granarium* being quite common.

Small stores are usually built of mud or fired brick of sizes of 4 x 4 x 4 meters mainly in villages. A large number of hanger- type warehouses are owned by government and semi–government agencies (Krishnamurthy *et al*. 1987).

In southern Sudan, local storage structures are mainly mud bricks or (Gugu). Baskets, bags are locally available and the cost is little (Darling 1959).

Silo – storage was adopted in the Sudan for the first time in 1967, when two modern concrete silos were constructed in Gradaref (100.000 tons) and Port Sudan (500.000 tons).

As far as infestation and damage to stored grains are concerned, the situation in the silos is far better than that found in the other storage premises. Strict measures are taken in the silos for the introduction of insect – free grains (Saad, 1978).

Moreover, the condition of the stored grains, that is the moisture content, the temperature and the development of any infestation, are regularly checked.

2.10. Control of the flour beetle.

Basically, control is aimed at the crevices, where the insect hides within bagged products. Several physical and biological methods are used (Shazali 1987, Mc Ganghey, 1976).

2.10.1. Hygiene methods.

Hygiene is the first step towards minimizing losses caused by the pests during storage. Cleanliness of the premises is one of the most important means of minimizing losses caused by pests during storage. The removal of residues and dirt would also make pesticide treatments effective (Krishnamurthy *et al*.1987)

2.10. 2. Physical methods

The physical methods which are used to minimize the number of insects are: keeping the temperature beyond the optimum range for the insects, reducing the moisture content of the grains to a lesser extent than that needed by the insects for development, irradiation, sticky traps, sieving, sunning, cold storage (Shazali, 1987) and airtight storage such as in the underground pits (matmoras), drums, plastered bins and plastic bags (McFarlane 1970).

2.10.3. Biological methods.

These include many natural enemies, such as predators and parasites mainly hymenopterous and hemipterous species attacking some insects of stored products, but the intensive use of pesticides applied to the stores caused drastic reduction in their populations. For this reason attempts have been made to use these natural enemies (Shazali1987). The only successful biocontrol method, which may economically be applied is the use of the bacterium, *Bacillus thuringiensis* (Mc. Ganghey 1976).

2.10.4. Chemical control

The types of chemical available for use against insect pests of stored products are some fumigants (curative treatment) and also some liquid and powder formulations of contact insecticides (prophylactic treatment).

2.10. 4.1. Fumigation

Fumigation does not prevent re-infestation, unless preventive measures are taken (Shazali, 1987). Fumigants leave some residues in the grains if carried out repeatedly, and the residues may rise beyond the tolerance limits and render the grains unsuitable for human and animal consumption (Krishnamurthy *et al*.,1987).

It should be remembered that fumigation is only a curative method, that can eliminate all stages of all species of stored grain insects, but when the fumigant is allowed to escape during the degassing operation, the grains are may be re-infested once again (Krishnamurthy *et al*.,1989).

The uptake of the fumigant, phosphine, by various stages of *Tribolium* spp. was found to be considerably greater in larvae and adults than pupae and eggs. The order of tolerance to PH_3 fumigation of the various stages of *Tribolium* spp. was egg > pupa > adult >larva (Lindgren and Vincent, 1966, and Bond, 1980).

Erakay and Ozar (1978) found that methyl bromide applied at 15 mg/m^3 at an average temperature of 6°C with an exposure period of 24 hours, gave 100% mortality of both eggs and adults of *Trogoderma granarium*, *Rhizopertha dominica*, and *Tribolium* spp.

2.10.4.2. Prophylactic treatments

Receiving infested grain stocks in the warehouse is a source of infestation. In order to protect the stock from cross infestation, prophylactic treatment should always be coupled with store hygiene programs (Krishnamurthy *et al.*1987).

The substances used for prophylactic treatments were the inert materials such as woodashes, kaolin, bentonite, diatomaceous earth, activated clay, gypsum, calcium phosphate and vegetable oil (Hall, 1983).

The botanical insecticides used for this purpose were neem, pyrethrum, derris and extracts of roots of neem (Shazali, 1987).

The synthetic insecticides used for controlling the insect pests of stored grains, are Malathion (57%E.C), Actellic, Sumithion, DDVP, Lindane and pyrethroids (Krishnamurthy *et al.*1989).

The insecticides used against the pests of stored products are formulated mainly as emulsifiable concertrates (E.C) wettable powders (W.P) oil solutions and dusts.

The E.C formulations of contact poisons are most commonly used as residual spray deposits in stores, fabrics and the surfaces of bagged grains. A minimum dose from each insecticide must be used in order to give satisfactory control without any problems of undue persistence or residues on the stored commodities (Shazali 1987).

The commonly used insecticides to protect stored grains are lindane, Malathion, Pyrethrins (Prevett, 1975) Feritrothion and Actellic (FAO 1983). Malathion has been used extensively, for nearly 30 years, as grain – protectant in U.S.A in order to control pests of stored products, but it is now losing its effectiveness because of development of insect resistance (Leonard *et al* .1982).

In the Sudan, several mechanical and chemical control measures were adopted to reduce the losses caused by insects to stored products.

The mechanical measures included mainly the sweeping of the store premises, collection and destruction of infested crop residues.

The use of chemical pesticides to control store pests in the Sudan is limited. Sometimes the grains in rural areas are mixed with some inert materials such as wood ashes or katilsous (finely ground rock phosphate). In commercial and public stores the store premises are disinfected, mainly by applying Malathion.

During the period 1969-1970, and due to the high insect infestation, the Plant Protection Department (P.P.D) used methyl bromide, gamma BHC (56% W.P) and Malathion (57% E.C). (Abdel Shakour 1987).

The wrong application of Malathion, such as spraying on dusty floors helped the development of strains, which are resistant to Malathion. (Krishenamurthy *et al*.1987).

Hassan (1987) tested the resistance of eleven strains of *Tribolium castaneum* to Malathion and found that the strains differ in their susceptibility to Malathion, which indicates development of resistance to this compound, which has been in use for a long time.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Insect culture

The food material store of the Shambat Food Research Centre was visited. The red flour beetle, *Tribolium castaneum,* was recorded and then clearly identified on sorghum flour inside the store. The stock culture of the insects was taken from this infested sorghum flour. Before the experiment was started *T. castaneum* cultures were maintained on flours of wheat, sorghum, millet and rice. After three days, the adults were screened out from the flours using 60 mesh to the inch sieve. The adults were discarded and the mediums, containing eggs were kept in the rearing room. Females and males (0− 24hr.- old) pupae were separated and held in the rearing room so that adults of known age and sex could be obtained for tests. The sexes were determined in the pupal stage (Good, 1936). One to two week old adults of *T. castaneum* were used in all experiments since at this age, the daily oviposition rate of the female is known to be the highest (Shazali, 1982).

3.2. The food

Insect free stocks of sorghum, (Fatarita variety), millet (Baladi variety) and imported rice were obtained from the grain market at Khartoum. Wheat (Baladi variety) was obtained from wheat program of the Gezira Research Station (GRS). They were then sieved by a 10 mesh to the inch sieve to remove dusts and other impurities, washed with water and sun dried.

The flours were obtained by grinding the cereal grains using an electric grinder and passing them through a sieve of 60 mesh to the inch to separate and remove any coalesced particles. The flours were placed in a deep freezer in air – tight containers for at least 10 days to destroy any insects that might have been present. Four batches containing 500g each of the sorghum, wheat, millet and rice flours were sealed separately in clean bottles (15.5 x 9cm) and kept in the rearing room for subsequent use.

3.3. Morphology of the different stages of *T. castaneum*

Twenty (1 – 2 week-old) *T. castaneum* adults were placed in glass petri–dishes containing 45g sorghum flour and kept in the laboratory under ambient conditions.

The standard food for rearing *T. castaneum* was whole- wheat flour (Good, 1936), but during this test the standard food used was sorghum flour (Fatarita variety).

After 24 – 48 hours, the flour was sieved through a 0.25 mm mesh sieve which allowed the flour to pass through but retained the eggs. The eggs present were collected under the binocular microscope. A total of 80 (0 – 24hr.- old) eggs were immediately transferred into four disposable Petri-dishes, 20 eggs in each dish without food. These eggs were subjected to close and frequent binocular observations to monitor development.

On hatching, each (0-2hr.- old) larva was carefully picked up by a camel hair brush and placed in a separate small glass vial (5 x 1.2cm) containing about 250mg of sorghum flour. 40 such vials were set up. The first instar larvae were measured and then described.

The larvae were reared on sorghum flour which was examined daily for shed skins, the presence of which indicated the termination of an instar period and the emergence of the subsequent one.

The different larval instars, pupae and adults were also observed and described.

3.4. Life cycle studies of *T. castaneum* in sorghum flour

3.4.1. Egg incubation period

The life cycle studies were carried out at room temperatures in Shambat, Khartoum North and the experiments were laid in Randomized Complete Block Design (RCBD). Four periods were assigned for these studies:

19.October/ 2000, 24.October/20000, 21.September/2001 and 19. June/ 2002. During these periods the temperature ranges were 20.6 – 35.0°C, 21.4 – 37.9°C 19.9 – 35.3°C and from 25.4 – 38.6°C, respectively. Average relative humidities were 31.8%, 32.5%, 28.3% and 39%, and for these periods, respectively.

The standard food used in these experiments was sorghum (Fatarita variety) prepared by grinding the sorghum grain and passing it through a sieve of 60 mesh to the inch. This food was equilibrated to room conditions before use for two weeks.

One hundred (1 – 2 week- old) adult beetles were introduced in small glass Petri-dishes containing 45g sorghum flour and left for 24 hours to oviposit. The contents of each of the dishes were then sifted through a 0.25 mm mesh sieve and the eggs present were examined under the binocular microscope.

For each test a total of 80 (0 – 24hr.- old) eggs were immediately transferred into four disposable Petri-dishes, with 20 eggs in each dish without food. Daily examination was made to observe and record the emerging larvae and register the incubation period.

3.4.2. Larval, pupal and total developmental period in sorghum flour

The larval, pupal and total developmental period investigations were performed in uncontrolled laboratory conditions in Shambat. The trials were laid in Randomized Complete Block Design (RCBD).

Four periods were assigned for these studies: 19.October to 21 November/ 2000, 24.October to 25 November/ 2000, 21.September to 24. October/2001 and 19.June to 18. July/ 2002. During these periods the temperature ranged from20.6 – 35.0°C, 21.4 – 37.9°C 19.9 – 35.3°C and from 25.4 – 38.6°C, respectively. Average relative humidities were 31.8%, 32.5%,28.3% and 39%, and for these periods, respectively.

For assessing the developmental periods at the various experimental conditions described, hundred (0 – 24hr.- old) eggs were placed in a glass Petri-dish without food. On hatching, each (0 – 24 hours – old) larva was carefully picked up by a camel hairbrush and placed in a separate small glass vial (5 x 1.2 cm) containing 250 mg of sorghum flour. Fourty such vials were set up for each experimental period.

Pupation and adult emergence dates were recorded and the larval, pupal and total developmental periods were determined.

3.5. The Biology of *T. castaneum* on four cereal flours

3.5.1. Duration of development of the immature stages

The development of *T. castaneum* on wheat, millet, sorghum and rice flours, was determined under uncontrolled laboratory conditions at Shambat, Khartoum North and the experiments were laid in a Randomized Complete Block Design (RCBD).

The developmental periods (from egg to adult emergence) were investigated at the various experimental conditions on four periods:

14.January to 12.March/2002, 19.January to 15 March/2002.24. March to 5.May/ 2002 and 30.March to 4.May/2002. The laboratory temperatures during the periods of the experiment ranged from 17.4 to 32.8 with an average of 25.1ºC, 16.4 to 33.8ºC with an average of 25.1ºC, 20.6 to 38.3ºC with an average of 29.5ºC, and range from 22.0 to 42.5ºC with an average of 32.3ºC, respectively. The average relative humidities were 29.7, 29.1, 23.8 and 23.9%, for the periods, respectively.

For assessing the developmental periods of *T. castaneum* in each flour type stock cultures were made available by collecting adults of the insect from respective infested flours.

One hundred (1 − 2 weeks –old) adults from each flour type were introduced into four Petri-dishes containing 45grams of each flour type and left for 24 hours for egg laying. For each test a total of 80 eggs (0 – 24hr. –old) eggs were collected from each flour under a binocular microscope, into small glass vials (5 x 1.2cm). In each vial five (0 – 24hr. –old) eggs were kept together without food. 16 such vials were set up for each flour type. Incubation period was determined by observing the time of hatching of new larvae in each vial.

To determine larval, pupal and the total developmental period of *T. castaneum* on each of the flour types, each (0−24 hours –old) larva was carefully picked up by a camel hairbrush and placed in a separate small glass vial (5 x 1.2cm) containing 250 mg of flour. Daily examinations were made in search of shed skins on pupation, the insects were sexed and placed singly in glass vials without food. Pupation and adult emergence dates were registered and the larval, pupal and total developmental periods were determined.

3.5.2. Mean live weight of immature stages and adults of *T. castaneum*

At each of the experimental conditions described (in section 3.5.1), a set of four glass Petri-dishes were used, and one hundred (1 - 2 week – old) adults of *T. castaneum* from each flour type were introduced to these Petri-dishes containing 45 grams of the flour of each cereal and left for 24 hours for oviposition. When the larvae were two to three weeks old, they were weighed in lots of 50 using an analytical sensitive balance. The mean live weight of these 50 larvae in each replicate (16 replicates) were obtained and recorded to the nearest 0.1 milligrams.
Similarly the weight of the (24 – 48hrs. –old) pupae in each replicate, in lots of 25, was taken. On pupation, the insects were sexed and placed singly in vials without food. The newly emerged adults were weighed when one to two weeks old in lots of 50 to the nearest 0.1 mg.

3.5.3. Sex ratio

In experiments (3.5.1. and 3.5.2) the pupae (in each flour) were sexed and sorted out into males and females. At the pupal stage sexing was done on the basis of the external characters. The appearance of the ventral surface of the terminal abdominal segment of the pupa differs greatly in the males and females. The chief characteristic feature of this

segment in the male is a flat disc-like depression whereas in the female they are two cone –like appendages, similar in appearance to the urogomphi, but much shorter and relatively thicker (Good, 1936).
The ratio of males to females (sex ratio) was determined.

3.6. Population build up and weight loss in flours of wheat, millet, sorghum and rice due to feeding by *T. castaneum*

The loss in weight due to infestation by *T. castaneum* was determined in the four types of cereal flours. The intact grains were obtained by first passing uncleaned grains through a 10 – mesh to the inch sieve to remove dust and other impurities, then washed with water (physical cleaning) and sterilization by sun drying for grains was done. The flours were then prepared by using an electric grinder.

200 grams of each cereal flour type were placed in plastic dishes. 15 pairs of one to two weeks old *T. castaneum* adults were introduced in each dish. The dishes were covered using muslin cloth inserts in the lid ring to facilitate ventilation, to prevent contamination with dust and to exclude other insect species.

The experiment was laid in a Randomized Complete Block Design (RCBD) with four replications.

Dishes were weighed at zero time (the beginning of observations) then routine weighing was continued at monthly intervals (for three months).

Monthly records of weight loss in the different treatments were taken.

Before weighing, the food in the infested dishes was sieved by 60 – mesh to the inch sieve to screen out insects. The food was weighed and the loss in weight determined. The number of live adult insects were determined and recorded. After counting, the live adults were returned to the dishes and dead adults were discarded.

The net weight loss due to insect feeding at different storage periods was obtained by subtracting the flour weight in the infested from the flour's initial weight. The differences in the weight of the flour of the control at different storage periods were very minute to the extent that they can be ignored.

The period of the experiment extended from the beginning of March till end of May/ 2001.The laboratory temperature during the period of the experiment ranged from 22.9ºC to 40.7ºC with an average of 31.8ºC and the relative humidity ranged from 11 % to 22.7% with an average of 16.9%.

For assessment of the relative susceptibility of these four cereal flours the aspects examined at the end of each month period of storage were the loss in weight (in grams), the percentage of loss in weight, and population build up (number of live adults) of *T. castaneum.*

3.7. Chemical composition of cereal flours

In the biochemistry laboratory of the Faculty of Agriculture, University of Khartoum, quantitative and qualitative chemical analysis of the four tested cereal flours were made to determine the % of moisture content, ash content, fat content, crude fibre, crude protein and carbohydrates.

Each flour sample was analyzed chemically in triplicate then averaged. The proximate analysis for each flour type was conducted according to the methods of AOAC (1984)

3.8. Data Analysis

The data were analyzed using (ANOVA) conducted with Duncan's multiple range test to determine the significance of differences at 0.05 probability level. Comparisons between means of treatments for various parameters measured were made by Standard error calculation (Gomez and Gomez, 1984 and Laoata, 2001). The objective of the statistical analysis was also to separate the variation due to experimental uncontrolled conditions from the variation due to type of food and other intrinsic factors.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Morphology of the different stages of *T. castaneum*

4.1.1. Egg stage

The egg is whitish in colour, cylindrical with rounded ends with flour particles adhering to the sticky surface. The egg becomes turgid as it approaches eclosion. Dead eggs first become rounded and hyaline in colour, they then collapse and shrivel gradually.

The surface of the egg is sticky as indicated by the flour particles adhering to it, which make its detection difficult (Good 1933, 1936; Hem Singh and Mohansingh, 1950 and William 1991).

4.1.2. Larval stage

During the present study the number of larval instars is found to range between six and seven (Table 1). The first larval instar is tiny, worm-like, whitish and with a prominent head. The antennae are very small and undifferentiated into segments. The compound eyes are very small. The body is convex dorsally but is slightly flattened ventrally. The body is composed of twelve segments, three thoracic and nine abdominal segments. There are three pairs of legs, one on each of the thoracic segments. Each segment bears two lateral pairs of fine whitish setae. The last abdominal segment carries a pair of brown appendages. The second to the seventh instars are morphologically similar and differ from one another only in colour and size. It was observed that the colour of these instars ranges from very light – brown to brown, with dark - brown narrow transverse strands on each segment. These strands grow darker and darker with the final instar. Larval colour is pale white immediately after moulting, with no strands on the segment, but after a while it becomes brownish and the dark brown strands become visible.

Table (1) shows the measurements of the body length of *T. castaneum* reared on sorghum flour. It can be seen that the length of the fully grown larva ranged between 5.8 and 6.0 mm. This is slightly different from the results of Good (1936) and Abdelsamad (1985) who found that the body length of the fully grown larva to range between 6.8 and 7.1mm. William (1991) stated that the larvae are white tinged with yellow and pass through 5 – 11 moults before reaching a full – grown length of 5mm.

4.1.3. Pupal stage

The pupa of *T. castaneum* is of the exarate type, (the antennae, elytra, and legs are free but closely pressed against the body), with a body length of about 4 mm (Table 1). When first transformed, the pupa is white but shortly afterwards the thoracic and abdominal regions become more distinct by taking on a creamy colour. The tarsal claws, the tips of the mandibles, and the terminal spines (called the urogomphi) turn dark – brown when the pupa is nearly mature (Frank, 1960). The pronotum is rather broad and protrudes anteriorly over the head, almost covering it from the dorsal side. The abdomen consists of six segments each bearing lateral tufts or brown setae similar to those observed in the larvae but the pupal tufts are shorter and thicker by comparison.

Differentiation between the two sexes is possible at the pupal stage. The shape of the depression separating the urogomphi is different in the two sexes. While flat and circular in the male, it is cone – like in the female (Good, 1936).

The results obtained in this study confirm those of Abdelsamad (1985) who found the average pupal body length to be 4.0 mm, but they are slightly different from those of Good (1936) who reported an average pupal body length, not including the urogmophi, of 3.35 mm.

4.1.4. Adult stage

The adult is a small beetle with a mean body length of between 4 and 5 mm (Table I). The antennae are well developed and are eleven segmented. The terminal three antennal segments are much larger than the preceding ones (club- shaped antenna). The body is flattened and reddish brown in colour. The elytra are striated and the head, thorax and abdomen are distinct. The sexes are more or less identical in appearance.

The measurements obtained during the present study are the same as those reported by Abdelsamad (1985) but are different from those of Good (1936) who recorded an average body length of 3.5 mm for both species of *Tribolium.* William (1991), repoted that adult of *T. castaneum* elongate, 2.6 – 4.4mmin length.

At adult stage the sexes can only be differentiated by the presence of a shallow pit in the venteral basal part of the fore – femur in the male, a character absent in the female (Halstead 1963). A confirmatory procedure for proper sex differentiation is to squeeze out the genitalia by applying slight pressure on the abdomen (Good 1936; Shazali 1982).

Table (1)

Measurements of the body length of the different stages of *Tribolium castaneum* reared on sorghum flour

Stage	Instar	Mean No. of Specimens measured	Body Length Maximum mm	Minimum mm	$\overline{X}$ ± S.E mm
Larva					
	1 st.	19	1.00	0.90	0.98 ± 0.006
	2 nd.	17	1.90	1.40	1.65 ± 0.046
	3 rd	16	2.50	2.30	2.35 ± 0.036
	4 th.	15	3.10	2.90	3.00 ± 0.028
	5 th.	14	3.60	3.50	3.76 ± 0.229
	6 th.	14	4.50	4.00	4.28 ± 0.064
	7 th.	14	6.00	5.80	5.84 ± 0.023
Pupa	-	23	4.00	4.00	4.00 ± 0.000
Adult	-	21	5.00	4.00	4.52 ± 0.340

4.2. Life cycle studies of *T. castaneum* on sorghum flour

4.2.1. Egg incubation period

Dates of egg laying and egg hatching of *T. castanaum* reared at room condition at the four test periods are shown in (Appendix 1.1. a, b, c, and d). The duration of incubation development at the four periods are presented in table (2).

High significant differences were obtained in egg incubation period recorded between the last period (June) and the other three periods of the study. In October, two periods, (temperature ranged from 21.0 – 36.5°C with R.H averaged 32.1%), the mean egg incubation period was 9.75 (± 0.297) days.

However, in September and June (temperatures ranged from 19.9 to 35.3°C and from 25.4 to 38.6°C with R. H. averaged 28.3 and 39.0%, respectively), the mean incubation periods were 10.00 and 6.25 (± 0.297) days, respectively, Table (2).

The data indicate that the incubation periods decreased with an increase in room temperature, and the rate of egg development increased with the increase in room temperature. Thus the shortest incubation period was in June (higher temperature) and the longest in September and October (lower temperature).

Similarly the highest rate of development during egg period was in June, and lowest rate of development was in September and October.

Several previous authors investigated the subject at different constant temperature and humidity regimes as well as at fluctuating uncontrolled conditions and obtained varying results.

The results presented here are in agreement with those of other workers. Abdelsamad (1985), who conducted an investigation in controlled conditions at 25°C, reported a mean egg period of 8.0 ± 0.75 days which is lower than the duration of 9.75 ± 0.297 days obtained in this study in uncontrolled laboratory conditions (at temperature range of 21.0 – 36.7°C). It is evident that the egg incubation period is very much influenced by temperature than relative humidity, an observation also made by other investigators (Khalifa and Badaway 1955b; Good 1936).

Table (2):

Effect of different un controlled laboratory conditions on incubation periods of *T. costaneum* on sorghum flour.

Period	Lab. Conditions Temp. range (C°)	Mean R.H (%)	Incubation Period Days)
19 October to 29 Nov. 2000	20.6 – 35.0	31.8	9.75 (a)
24 October to 25 Nov. 2000	21.4 – 37.9	32.5	9.75 (a)
21 September to 24 Oct.2001	19.9 – 35.3	28.3	10.00 (a)
19 June to 18 July 2002	25.4 – 38.6	39.0	6.25 (b)
		S.E (±)	0.297**

** = Significant differences at 1% level.

- Values are means (±) S.E
- Means not sharing a common subscript letter in a column are significantly different at $P \leq 0.05$ as assessed by Duncan's multiple range test.

4.2.2. Larval, pupal and total developmental period in sorghum flour

a. Larval duration

Date of each moulting of *T. castaneum* (from first to seventh moult) in uncontrolled conditions at different test periods are presented in (Appendix 1.1. a, b, c, and d).

It can be seen from (Table 3) that the shortest larval duration of *T. castaneum* (15.50 ± 0.331 days) was obtained at a temperature range of 25.4 – 38.6°C, while at temperature range of 19.9 – 35.3°C, the longest mean larval duration was (17.25 ± 0.331 days). These results indicate that under the uncontrolled conditions of the experiment, there was only slight difference in the larval duration, but still a decrease in temperature results in slower development (Table 3). The results also indicate that temperature plays a very significant role in the rate of larval development.

T. castaneum had varying numbers of larval instars at the different uncontrolled laboratory conditions tested. The number ranged from six to seven instars. It is clear that at mean laboratory temperatures less than 30°C, all the larvae had 6 instars. At a mean temperature of 32.0°C, however, none of the larvae underwent 6 instars they all had 7 instars. The duration of the different instars differed according to temperature as shown in (Table 4).

The shortest duration was shown by the first instar, the longest by the last instar, while those of the instars in between were intermediate and more or less equal.

The present results generally agree with those of Abdelsamad (1985), who found that the mean larval duration at uncontrolled laboratory conditions (mean temperature 30.4°C and mean R.H.44.1%)

was 21.97 ± 0.31 days, which is longer than the larval duration obtained in this study, 17.25 ± 0.331 (temperature ranged from 19.9 to 35.3°C and mean R.H. 28.3%) days under uncontrolled laboratory conditions (mean temperature 27.26°C and mean R.H.30.7%).

Abdelsamad (1985) also reported that the numbers of larval instars ranged from 6 to 8 instars with 7 instars as the most frequent. Khalifa and Badawy (1955 b) reported a short larval period of 21.1 days in August, (at mean temp. 30°C) which approached the period (17.25 days) found in October in this work under uncontrolled laboratory conditions. Different results were obtained by Good (1936) who maintained that controlled 30°C was the optimum temperature for the larval development (22 days) of *T. castaneum* in whole wheat flour.

A possible explanation for the discrepancy between Good (1936) and the present results may be attributed to that Good (1939) used controlled temp. (30°C) while the present work used uncontrolled conditions. Also the larval food used by Good (1936) is wheat flour while the food used during the present work is sorghum flour.

It is documented in the literature that different types and forms of food on which *T. castaneum* was reared contribute to the variability in the speed of larval development. Khalifa and Badawy (1955 b) reported that *T. castaneum* larvae reared on whole wheat flour had about 6 instars but those reared on crushed wheat had up to 8 instars. They also stated that wheat was a more suitable larval food than corn.

Good (1936) stated that there was no fixed number of larval instars in *Tribolium* spp., the number ranging between 5 and 11 or even more, but the usual number was seven or eight. In the present study, however, the maximum number of larval instars recorded was 7, but the most frequent number was 6 (Table 4).

Good (1936) explained that the variation in the number of larval instars was due to both the external conditions (such as temperature, humidity and food) and the strain of insect. Wigglesworth (1950) also confirmed the above statement. Khalifa and Badawy (1955 b) showed that the duration of the first instar was the shortest whereas that of the last instar was the longest. They also stated that the instars in between were about equal in duration but the second instars tended to be of somewhat longer duration. These findings of Khalifa and Badawy (1955 b) agree well with the results in the present study (Table 4).

b. Pupal period

Dates of pupation at different uncontrolled laboratory conditions in the current study are given in Appendix (1.1.a, b, c, and d). Significant differences were found in pupal period of *T. castaneum* at different uncontrolled laboratory conditions (Table 3). The shortest mean pupal period of *T. castaneum* (4.25 ± 0.270 days) was observed at temperature range of 25.4 – 38.6°C. At ranges of 21.4 – 37.9°C and 19.9 – 35.3°C the mean pupal durations were 4.75 ± 0.270 days and 4.50 ± 0.270 days, respectively (Table 3).

Good (1936), and Khalifa and Badawy (1955 b), stated that the duration of the pupal period seemed to be less affected by external conditions than did the egg or the larval periods.

Good (1936), recorded the pupal period as 4 – 6 days at 30°C, 6 - 8 days at 27°C, 6 – 12 days at 25°C and 4 – 5 days at room conditions during the early summer (mean temperature 22°C and mean R.H. 32%). Howe (1956) also reported that the larval food did not affect the pupal

period. The present results thus confirm the findings of Khalifa and Badawy (1955 b), Howe (1956) and Abdelsamad (1985).

c. Total developmental periods

Date of adults emergence of *T. castaneum* under uncontrolled laboratory conditions are shown in Appendix (1.1. a, b, c, and d).

The average total developmental periods from oviposition to adult emergence under the four laboratory conditions are given in (Table 3). Highly significant differences were obtained in total development periods recorded between the last period (June/July) and the other three periods. The shortest mean developmental period was (26.00 ± 0.637 days) obtained in June/July at temperature range of 25.4 – 38.6°C. At temperature ranges of 20.6 – 35.0°C and 19.9 – 35.3°C, the total longest durations were 32.00 and 31.75 (± 0.637 days), respectively (Table 3).

The total developmental period from egg to adult varies considerably according to the prevailing environmental conditions particularly the temperature (Table 3).

Abdelsamad (1985), stated that at fluctuating temperature and humidity in the laboratory (mean temperature 30.4°C and mean R.H. 44. 1%) the total developmental period of *T. castaneum* was 29.94 days, which is close to the total developmental period obtained during the present study (at range of temperature 21.4 – 37.9°C and mean R.H. 32.5%).

Howe (1956) concluded that the development of a complete generation of *T. castaneum* is possible within a period of one month at temperatures over 30°C and relative humidities in excess of 30 %.

The present findings on the total developmental periods at different fluctuating laboratory conditions are in agreement with those obtained by Howe (1956).

Table (3): Effect of different uncontrolled laboratory conditions on larval, pupal, and total developmental periods of *T. castaneum.* On sorghum flour

Period	Lab. Conditions Temp range (C°)	Mean R.H (%)	Larval period (days)	Pupal period (days)	Total develop. Period (days)
19 Oct. to 21 Nov./ 2000	20.6 - 35.0	31.8	16.75 (a)	5.50 (a)	32.00 (a)
24 Oct. to 25 Nov./ 2000	21.4 - 37.9	32.5	16.25 (ab)	4.75 (ab)	30.75 (a)
21 Sept. to 24 Oct./ 2001	19.9 - 35.3	28.3	17.25 (a)	4.50 (b)	31.75 (a)
19 June to 18 July /2002	25.4 - 38.6	39.0	15.50 (b)	4.25 (b)	26.00 (b)
		S.E (±)	0.331*	0.270*	0.637**

* = significant differences at 5% level

** = significant differences at 1% level

- Values are means (±) S.E
- Means not sharing a common subscript letter in a column are significantly different at $P \leq 0.05$ as assessed by Duncan's multiple range test.

Table (4):
Duration of the larval instars of *T. castaneum* at different uncontrolled laboratory conditions in sorghum flour

Lab. Conditions Temp. Range (C°)	Mean R.H (%)	1st instar	2nd instar	3rd instar	4th instar	5th instar	6th instar	7th instar
20.6 – 35.0	31.8							
Range		1 – 2	3 – 4	2 – 3	2 – 3	2 – 3	4 – 5	
Mean		1.75	3.50	2.25	2.25	2.25	4.75	
21.4 – 37.9	32.5							
Range		1 – 2	3 – 4	2 – 2	2 – 2	2 – 4	3 – 4	
Mean		1.75	3.75	2	2	3	3.75	
19.9 – 35.3	28.3							
Range		2–2	3 – 4	2 – 4	2 – 3	2 – 4	3 – 4	
Mean		2	3.50	2.50	2.50	3	3.75	
25.4 – 38.6	39.0							
Range		1–2	3 – 3	2 – 2	2 – 2	2 – 2	2 – 2	3 – 4
Mean		1.40	3	2	2	2	2	3.2

4.3. Biological studies on *T. castaneum* reared on four cereals flours

4.3.1 Duration of development

4.3.1.1. Egg incubation period

Appendix (2.1.a) shows the analysis of variance for egg incubation period of *T. castaneum* reared at different laboratory conditions and fed on flours of millet, wheat, sorghum and rice. Significant differences existed in egg incubation periods between rice and other flour types when the insect was reared on different laboratory conditions (Table 5).

The mean egg incubation periods were 8.3, 8.1, 8.1 and 9.4 days on wheat, millet, sorghum and rice flours, respectively (Table 5). Thus, the longest mean incubation period was found on rice flour (9.4 days), on the other flours the egg incubation periods were almost the same.

The results show that variations in the egg incubation periods were little on the different types of flours. These results confirm the conclusion of Good (1936) who stated that type of food had no effect on the egg incubation period of *T. castaneum*.

4.3.1.2. Larval development period

Data on larval development of *T. castaneum* (from egg hatching to pupation) at the various fluctuating experimental conditions in flours of wheat, millet, sorghum and rice are given in (Table 5) and Appendix (2.1.b). Larval periods were significantly different when the insect was reared under the different uncontrolled laboratory conditions and also different flours (Table 5).

Generally, there was a decrease in larval period with the increase of temperature range under which the insects were reared. At the highest range of temperature (22.0 – 42.5°C), the shortest larval period was attained on millet flour (16.8 days), whereas the longest was on rice flour (21.5 days) (Table 5).

The larval period differs according to the diet. It can be seen from (Table 5) that the average larval periods at the different laboratory conditions were 18.5 days on millet, 23.2 days on wheat, 23.5 days on sorghum and 30.6 days on rice flour.

Thus, the shortest mean larval durations were attained on millet flour and the longest on rice flour with wheat and sorghum flours, somewhere in between (Table 5).

The results indicate that the flours of millet, wheat and sorghum were favourable for high rates (fast) of larval development, while rice flour under the same experimental conditions resulted in significantly slower rate of larval development. The results also indicate that food significantly influences the rate of larval development.

Khalifa and Badawy (1995b) showed that different types and forms of food on which *T. castaneum* was reared affected the speed of larval development. They concluded that larvae reared on whole-wheat flour had shorter larval periods than those reared on crushed wheat.

They also stated that wheat was a more suitable larval food than corn (maize). Good (1933) suggested that the variation in the larval duration could be due to both the external conditions (such as temperature, humidity and food) and the strain of the insect. Wigglesworth (1950) also confirmed the above statement.

Good (1936) reported that the duration of the larval period could range between 22 to over 100 days according to the environment and to the variation between individuals. He added that, of the foods used, whole-wheat flour was the most favourable for larval development.

Abdelsamad (1985) recorded a larval period of 21. 97 ± 0.31 days on sorghum flour (at mean temperature of 30.4°C and mean R.H of 44.1%) which is close to the results obtained on sorghum in the present study.

Hassan and Khan, (1988) studied growth and development of the red flour beetle, *T. castaneum* on wheat and lentil flour at 30°C and 85 % R.H. They found that the larval period was much shorter for the insects reared on wheat flour (17.91 days), than those on lentil flour (39.15 days). Singh *et al*. (1992) studied the biology of *T. castaneum* on wheat, chickpea, bajra (= Pearl millet) and maize flours in the laboratory at 15 – 36°C and 52 – 71% R.H. They reported that the larval period lasted 159.5, 162.0, 153.5 and 163.5 days on wheat, chickpea, bajra (= pearl millet) and maize flours respectively.

White and Loschiavo, (1988) concluded that the rate of larval development of *T. castaneum* was slower on oat than on wheat. It is evident that the results obtained in this study are in agreement with those obtained by Hassan (1988), Singh *et al*. (1992) and White and Loschiavo (1988) and that both millet and whole-wheat flours are the foods causing the most rapid larval development of *T. castaneum*.

4.3.1.3. Pupal development period

Appendix (2.1.c) shows the analysis of variance for pupal duration of *T. castaneum* kept at different laboratory conditions and fed on flours of millet, wheat, sorghum and rice. Highly significant differences were obtained in pupal periods between rice and other flour types when *T. castaneum* was reared at different laboratory conditions (Table 5). The average pupal periods were 5.3, 5.3, 5.5 and 6.0 days on millet, wheat, sorghum and rice flours, respectively (Table 5).

Thus, the longest mean pupal period was found on rice flour (6.0 days), on the other flours the pupal periods were almost the same.

The results show that variations in the pupal durations were little, although the larval foods were different. Similarly the rates of pupal development on the different types of flours were more or less the same. Hence, these results confirm the conclusions of Good (1936) and Howe (1956) who stated that larval food had no effect on the pupal period of *T. castaneum*.

Hassan and Khan (1988) reported a pupal period of 5.23 days on wheat flour (at 30°C and 85 % R.H), which is similar to the pupal period of 5.3 days found on wheat during the present study.

Singh *et al*. (1992) stated that, the pupal period (at 15 –36°C and 52 – 71% R.H), lasted 8.5, 8.0, 6.0 and 6 – 2 days on wheat, chickpea, bajra (= pearl millet) and maize flours, respectively. The pupal period obtained by Singh *et al*. (1992) on millet flour is slightly longer than that found on the same food in this study, 5.0 ± 0.68 days under uncontrolled laboratory conditions (at 16.4 – 33.8°C and mean 29.1% R.H.).

4.3.1.4 Total developmental period

The results obtained show that both food and laboratory conditions had significant effects on the total developmental duration of *T. castaneum*. (Table 5 and Appendix 2.1.d).

The average total developmental periods from egg to adult emergence on the four flours tested are given in (Table 5). The shortest average total developmental period over all conditions was 31.9 days obtained on millet flour, and the longest was 45.9 days occurring on rice flour. Total developmental periods for wheat and sorghum were 36.8 and 37.1 days, respectively (Table 5).

The results also show that both the average total developmental period and the rate of total development of *T. castaneum* on wheat flour were close to those on sorghum flour, while the average total developmental period on millet flour was the shortest and that on rice flour the longest (Table 5). With respect to the rate of total development, the millet flour appears to be the most favourable (with faster rate of development) and rice flour the least (with slower rate of development).

The results presented here are generally in agreement with those of other workers. Abushama *et al*, (1987) reported that whole wheat flour and semolina were more suitable than whole rice flour and broken (crushed) wheat for the development of the different stages of the *T. castaneum*.

Imura (1991) studied growth and development of *T. castaneum* and reported that the insect generally developed well on cereal seeds (rice, wheat and maize) and their products.

Sattigi *et al*, (1995) investigated the biology of *T. castaneum* on whole flour of rice, wheat, maize and sorghum under uncontrolled laboratory conditions at 24 −29°C and 70% R.H and concluded that with regard to development, wheat flour was the most suitable while rice flour was the least, which agreed with the results of the current investigation.

Table (5) Duration of development (Days) of the immature stages of the beetle *T. castaneum* reared on flours of wheat, millet, sorghum and rice under uncontrolled laboratory conditions.

Flour Type	Lab. Condition Temp. range Mean °C	R.H %	Egg incub. Period (Days)	Larval Period (Days)	Pupal Period (Days)	T. develop. Period (Days)
	17.4 – 32.8	29.7	12.9	24.4	5.4	42.8
Wheat	16.4 – 33.8	29.1	10.8	25.4	5.4	41.5
	20.6 – 38.3	23.8	5.5	25.0	5.0	35.4
	22.0 – 42.5	23.9	4.0	18.0	5.5	27.5
Mean			8.3 (b)	23.2 (b)	5.3 (b)	36.8 (b)
	17.4 – 32.8	29.7	12.0	20.0	5.5	37.5
Millet	16.4 – 33.8	29.1	11.0	20.3	5.0	36.3
	20.6 – 38.3	23.8	5.5	17.0	5.0	27.5
	22.0 – 42.5	23.9	4.5	16.8	5.5	26.3
Mean			8.1 (b)	18.5 (c)	5.3 (b)	31.9 (c)
	17.4 – 32.8	29.7	13.0	22.1	5.1	40.3
Sorghum	16.4 – 33.8	29.1	10.0	27.5	5.4	42.9
	20.6 – 38.3	23.8	5.5	26.1	5.8	37.4
	22.0 – 42.5	23.9	4.0	18.3	5.8	28.0
Mean			8.1 (b)	23.5 (b)	5.5 (b)	37.1 (b)
	17.4 – 32.8	29.7	14.5	36.5	5.9	56.9
Rice	16.4 – 33.8	29.1	12.0	36.5	5.5	54.0
	20.6 – 38.3	23.8	6.0	27.8	6.5	40.3
	22.0 – 42.5	23.9	5.0	21.5	6.1	32.6
Mean			9.4 (a)	30.6 (a)	6.0 (a)	45.9 (a)
S.E (±)			0.072**	0.405**	0.112**	0.396**

** = Significant differences at 1% level

-Values are means (±) S.E

-Means not sharing a common subscript letter in a column are significantly different at P ≤ 0.05 as assessed by Duncan's multiple range test.

4.3.2. Mean live weight of immature stages and adults of *T. castaneum*.

The mean live weight of the different stages (larva, pupa and adult) of the beetle *T. castaneum*, reared under uncontrolled laboratory conditions on flours of wheat, millet, sorghum and rice, are shown in Table (6). Analysis of variance (ANOVA) for mean weight of the different stages of the insect is shown in Appendix (2.2.a.b.c). The results obtained show that food had a significant effect on the mean weight of the different stages (larva pupa and adult) of the insect reared under different laboratory conditions (Table 6).

The results indicate that the mean weight of larva, pupa and adult were less for insects reared on millet, sorghum and rice than those reared on wheat flour. Thus the mean live weight of the larva reared on wheat flour was 1.73 mg, which was heavier than that of the larva reared on rice flour (0.90 mg). Similarly the mean weights of the pupa and adult reared on wheat flour were 2.42 mg for the pupa and 2.00 mg for the adult, which were heavier than those individuals reared on rice flour (1.91 mg for the pupa and 1.55 mg for the adult). It appears that wheat is superior to the other types of flours and that it has a higher nutritional value for *T. castaneum.* Similar findings were reported by Good (1936), Abdelsamad (1985) and Hassan and Khan (1988). These authors found that wheat flour was superior to all other types of flours and it enhanced the body weight of all the stages of *T. castaneum*.

Table (6):

Mean live weight (in milligrams) of the different stages of *T. castaneum*, reared on the four cereal flours under uncontrolled laboratory conditions[1].

Flour	Mean wt. of (2-3) weeks old larva	Mean wt. of (24-48hr.) old pupa	Mean wt. of (1-2) week old adult
Wheat	1.73 (a)	2.42 (a)	2.00 (a)
Millet	1.68 (ab)	2.13 (b)	1.75 (b)
Sorghum	1.43 (b)	2.09 (b)	1.69 (b)
Rice	0.90 (c)	1.91 (b)	1.55 (c)
S.E (±)	0.078**	0.077**	0.045**

1 = Temp. Ranges 16.4 – 33.8°C and 20.6 – 42.5°C
R.H means 29.0% and 23.0%

** = Significant differences at 1% level.

- Values are means (±) S.E.

- Means not sharing a common subscript letter in a column are significantly different at $P \leq 0.05$ as assessed by Duncan's multiple range test.

4.3.3 Sex ratio

The mean number of pupae examined and the number of males and females and the sex ratios of *T. castaneum* reared under fluctuating laboratory conditions on flours of wheat, millet, sorghum and rice, are presented in (Table 7) and the percentages of males and females are illustrated graphically in (Fig. 3).

The results show that more females were produced in the flours of millet, wheat and sorghum than males. However in the insect culture raised on rice the males out numbered the females. Thus the ratio of males to females was close to unity on sorghum flour, greater than unity both on millet and wheat flours, and less than unity on rice flour (with more males than females). No records have been found in the literature about the effect of food on the sex ratio of *T. castaneum*. Hence further investigations may be required to elucidate this finding.

The sex ratio (% males to females) of *T. castaneum* obtained by Good (1936) on whole wheat flour at 30°C (1 : 1.3) is similar to the sex ratio found during the present work in the same food under fluctuating laboratory conditions. Abdelsamad (1985) reported that the ratio of males in relation to females, on sorghum flour, was 1:0.9, 1: 0.7, 1:1.4 and 1:1.4 at 25°C, 30°C, 35°C and at fluctuating laboratory conditions respectively. Thus the sex ratio obtained by Abdelsamad (1985) at fluctuating laboratory conditions (mean temp. 30.4°C and mean R.H 44.1%) on sorghum flour (1:1.4) is similar to that found during the present study on millet flour.

Singh *et al,* (1992) studied the male to female ratios of *T. castaneum* in the laboratory at 15 - 36°C and 52 - 71 % R.H, and found that the sex- ratios were 1: 1.7, 1: 1.1, 1: 1.5 and 1 : 1.1, on wheat , chickpea , bajra (pearl millet) and maize flours, respectively.

The sex ratio of *T. castaneum* obtained by Singh *et al*, (1992) on maize flour (1:1.1) is similar to the sex ratio found during the present work on sorghum flour and that which was obtained on millet (1:1.5) is close to that found during the present study on the same food.

Both the present results and results of Singh *et al*. (1992) confirm that the sex ratio of *T. castaneum* was greater than unity, with slight predominance of females on the three flours (millet, wheat and sorghum). This may explain the considerable increase in the population of this insect when reared on millet, wheat and sorghum flours because there are always more reproductive females in the culture.

Table (7):

Mean sex ratio (males to females) of *T. castaneum* reared on flours of wheat, millet, sorghum and rice under fluctuating laboratory conditions.

Flour	No. of pupae	No. of males	No. of females	Males (%)	Females (%)	Sex–ratio (males: females)
Wheat	384	155	229	40.36	59.64	1:1.48
	360	171	189	47.50	52.50	1:1.11
Mean	372	163	209	43.93	56.07	1:1.3
Millet	384	194	190	50.52	49.48	1:0.98
	225	82	143	36.44	63.56	1:1.74
Mean	304.5	138	166.5	43.48	56.52	1:1.4
Sorghum	384	190	194	49.48	50.52	1:1.02
	384	181	203	47.14	52.86	1:1.12
Mean	384	185.5	198.5	48.31	51.69	1:1.1
Rice	384	232	152	60.42	39.58	1:0.66
	215	139	76	64.65	35.35	1:0.55
Mean	299.5	185.5	114	62.53	37.47	1:0.6

4.4. Population build up and weight loss in flours of wheat, millet, sorghum and rice due to feeding by *T. castaneum*

4.4.1. Weight loss of wheat millet, sorghum and rice due to feeding of *T. castaneum* over a period of three months.

The losses in weight (g) of flours of wheat, millet sorghum and rice caused by the feeding of *T. castaneum* over a period of three months are presented in (Table 8). Analysis of variance for weight loss of the four types of flour in different storage periods is shown in Appendix (3.a). Significant differences were recorded in weight losses among the four flours infested by *T. castaneum* at different periods of storage. The samples of flours of wheat and millet suffered more mean losses in weight (43.1 and 43.5g), respectively, than sorghum and rice (34.1 and 24.5g, respectively) (Table 8).

Marked increase in weight loss was observed after the first month of storage in all infested flours, particularly in wheat and millet flours. The loss in weight of wheat, millet, sorghum and rice flours incurred in the first month was less than that in each of the subsequent two months of storage.

With regard to the weight losses caused by *T. castaneum* feeding on flours over a three months period of storage, wheat and millet showed the highest losses (74.1 and 70.3g), respectively, whereas sorghum and rice showed the lowest (56.6 and 32.0g) respectively (Table 8).

This indicates that rice flour is the least suitable for the development of *T. castaneum* compared with the other three flour types.

The loss in weight increased with the storage periods on wheat, millet, sorghum and rice flours due to the build – up in insect numbers with time. The loss in weight of flour increased with the storage periods at a decreasing rate particularly in rice flour (Table 8).

Percentage weight losses of the different cereal flours due to the feeding of the red flour beetle over a period of three months are shown in (Table 8) and the percentage weight losses for each type of flour were illustrated graphically in (Fig. 1). Analysis of variance for percentage of weight loss in different storage periods is given in Appendix 3.b.

Percentage weight losses reflected significant differences among the different types of flours in the three periods of storage (Table 8).

Wheat and millet flours registered the highest levels of percentages of weight losses (37.0 and 35.2%), respectively, rice flour showed the lowest level of percentage of weight loss (16.0%), whereas the sorghum flour reflected moderate level of percentage of weight loss (28.3%) (Fig. 1). Thus, rice flour was the least, wheat and millet were the most susceptible to infestation.

Good (1936) stated that practically any kind of flour might be infested, especially whole wheat flour which seemed more liable to attack. Audery (1975) also found that in the laboratory, *T. castaneum* could develop well on cereal products, particularly on whole wheat products. Similarly Lecato (1975) and White (1982) 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. William (1991) also reported that both the confused and the red flour beetles primarily attacked milled grain products, such as flour and cereals.

The present results confirmed the ability of *T. castneum* to survive and develop well in all the four cereal flours (wheat, millet, sorghum and rice). Thus in stores where *T. castaneum* is really a serious problem, a practice may be developed to sieve the grains through suitable sieves to eliminate broken grains and flour before storage. This will at least partly reduce the initial infestation by this pest.

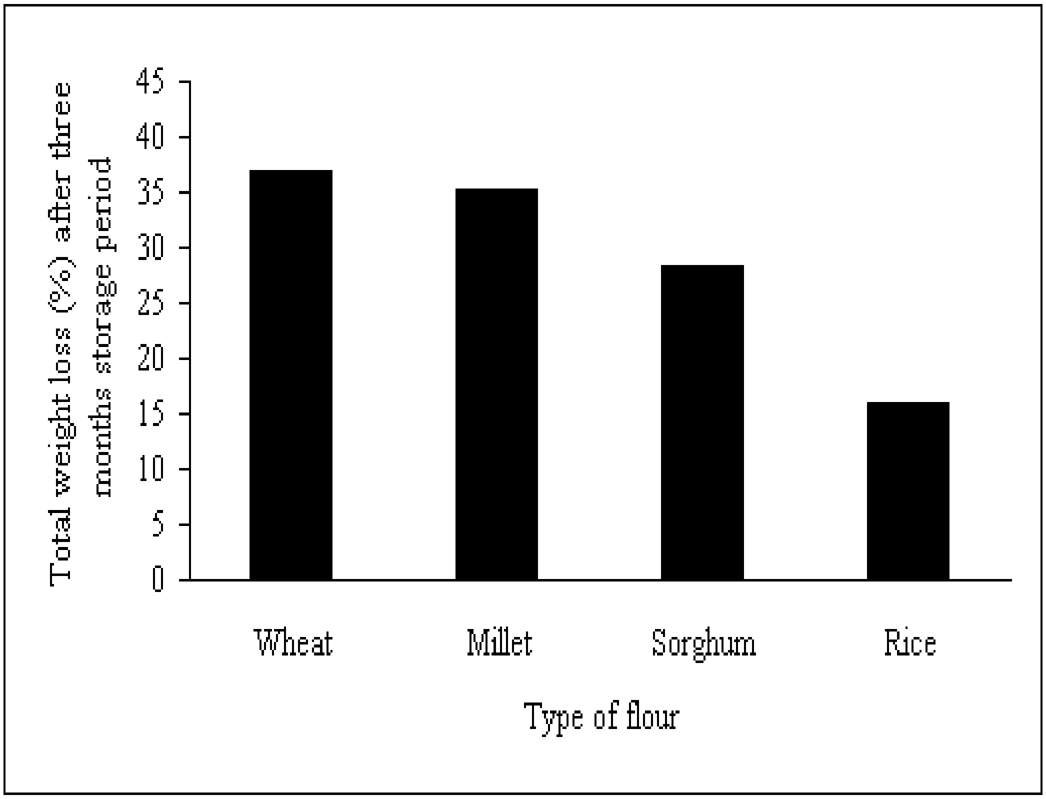

Fig (1): Weight losses (%) of Wheat, Millet, Sorghum and Rice flours caused by the feeding of *T. castaneum* over a period of three months.

4.4.2. Effect of storage period and food type on Population build – up

Monthly count of adults of *T. castaneum* encountered on the samples of different cereals flours, over a period of three months are shown in (Table 8) and the total alive adults of *T. castaneum* surviving in each food type at the end of three months period is presented in (Fig. 2).

Analysis of variance (ANOVA) of adults counted on each flour in different storage periods are given (Appendix 3.C).

Significant differences were obtained in number of live adults of *T. castaneum* counted at different periods of storage among the four flours wheat, millet, sorghum and rice (Table 8).

The total adult population of *T. castaneum* surviving in wheat flour at the end of three months storage period was 1554.0 (the highest) while that for rice was 365.3 (the lowest) (Fig. 2).

T. castaneum was present in appreciable numbers throughout the storage periods but the number of live adults increased markedly during the third month of storage (except on rice) (Table 8). The results also show that the mean number of live adults in wheat and millet flours (885.3 and 850.8), respectively, were greater than that in the other two types of flours, particularly in rice flour (254.3) (Table 8). It is evident that wheat and millet flours were the most suitable with regard to population build – up, while rice flour was the least.

Abushama *et al.* (1987) who investigated the food preference and feeding activity of *T. castaneum* in the laboratory concluded that wheat flour and semolina were more suitable than rice and crushed wheat for the development of the different stages of this insect. Imura, (1991) reported that *T. castaneum* generally developed well on seeds of wheat, rice and corn as well as on their products. Dayakar and Ray (1998) studied growth and development of *T. castaneum* and found that the number of adults in whole wheat flour were greater than in the flours of maize and rice. The high infestation of wheat flour was due to the high protein and amino acid contents of the seeds. The results of Dayakar and Ray (1998) agreed with the results obtained during the present work.

Thus, more susceptible products should be isolated if possible, so that they can be more carefully stored.

Table (8): Weight loss (g) percentage weight loss of wheat, millet, sorghum and rice flours infested by *T. castaneum* and the number of live adults of the insect over a period of three months.

Flour type	Storage periods (month)	wt. loss (g)	% wt. loss	No. of live adults
	1	13.6	6.8	28.0
Wheat	2	41.6	20.8	1073.8
	3	74.1	37.0	1554.0
Mean		43.1 (a)	21.5 (a)	8 85.3 (a)
	1	13.8	6.9	26.3
Millet	2	46.2	23.1	1254.0
	3	70.3	35.2	1272.0
Mean		43.5 (a)	21.7 (a)	850.8 (a)
	1	10.4	5.2	23.5
Sorghum	2	35.3	17.7	1016.8
	3	56.5	28.3	1104.5
Mean		34.1 (b)	17.1 (b)	714.9 (b)
	1	14.4	7.2	27.8
Rice	2	27.1	13.6	369.8
	3	32.0	16.0	365.3
Mean		24.5 (c)	12.3 (c)	254.3 (c)
S.E (±)		0.450**	0.255**	16.004*

* = Significant differences at 5% level.
** = Significant differences at 1% level
- Values are means (±) S.E

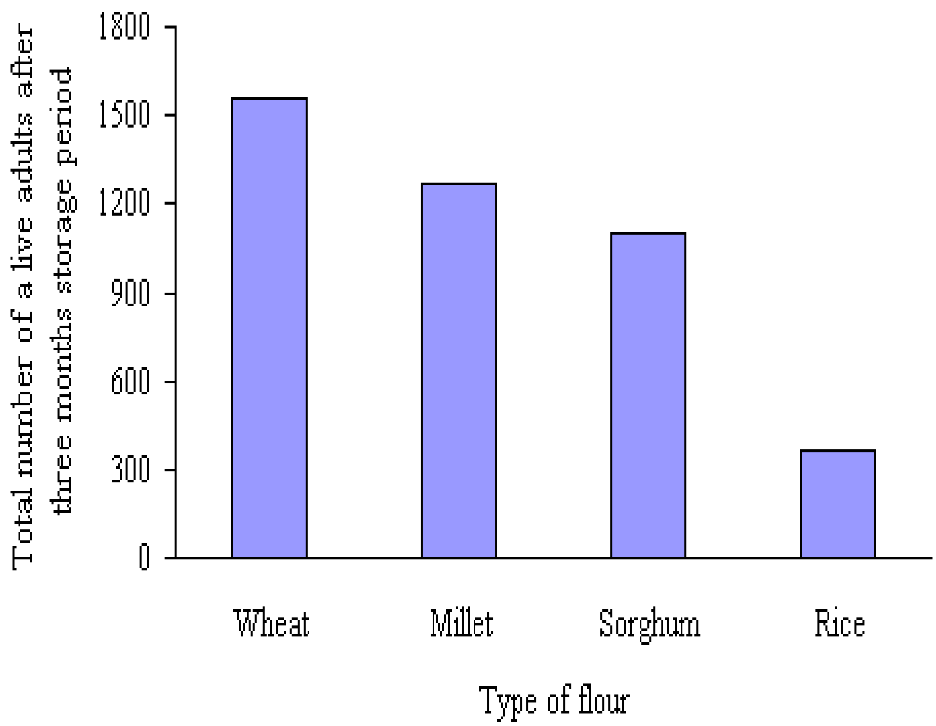

Fig. (2): Number of alive adults of *T. castaneum* surviving in flour of Wheat, Millet, Sorghum and Rice at the end of three months storage period.

4.5. Chemical composition of the flours of wheat, sorghum, millet and rice

The proximate chemical composition of the flours of wheat, millet, sorghum and rice are shown in (Table 9).

The nutritive value of a food source is largely dependent on its chemical composition, and foods deficient in proteins, for instance, or essential amino acids 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 grain flours are more suitable in enhancing development and multiplication of *T. castaneum,* we carried out an analysis of the chemical composition of these grain flours, as can be seen in (Table 9).

The differences between moisture contents of the different flours were not significant (Table 9). Generally, the level of moisture content in the flours was around 6%.

Percentages of ash contents were found to be highly significant between rice and other flour types. Ash contents in sorghum, millet and wheat were more or less the same (2.4%) and significantly higher than the rice flour (1.07%).

There were significant differences in oil content among the flours (Table 9). The differences among the three flours, millet (5.46%), sorghum (3.68%) and wheat (4.1%) were significant. The oil content of rice was significantly lower than the other three flours (2.30%).

The differences among the flours in protein content were highly significant. However, protein content of wheat (13.89%) and millet (12.87%) considered the same and were significantly higher than that of sorghum (10.15) and rice (8.05%).

Carbohydrate levels were found to be highly significant among the four flours, with rice showing the highest percentage (82.54%) and millet and wheat the lowest (73.30%).

Since the results showed lower amounts of ash, oil and proteins in rice than in the other three flours, this may explain to some extent why *T. castaneum* was not able to develop and multiply faster on rice flour because these ingredients are essential for growth. The finding that the rice flour had the highest carbohydrate content, followed by sorghum flour, while millet and wheat had the lowest amounts, can indicate that carbohydrates are important energy source, however their contribution to body building and total growth is rather limited.

Bains (1971) 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. Dalel and Gupta (1974), Phadke and Bhatia (1974) 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.

Breese (1963) observed that the oviposition rate of *T. castaneum* on two different varieties of rice was only slightly lower than that on wheat and attributed that to the difference in the nutritional values of these grains or possibly to the harder texture of the rice kernels, which limit the feeding rate and egg production. Abushama (1987) concluded that wheat flour was more suitable than rice for the development of the different stages of the *T. castaneum* and attributed this to the presence of adequate amounts of fats, proteins and carbohydrates in wheat flour and added that food materials of relatively small particle size were preferred to larger particles.

Bekon and Lessard (1988) studied the food-searching behaviour of young adults of *T. castaneum* on grains of soft wheat, maize, millet, barley, brown rice and sorghum and reported that the correlation between the biological value of these grains and insect development was explained mainly by the water and oil contents of the flour and the ratio of nitrogen to carbon. 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.

Longstaff (1995) studied the influence of the physical food quality on the population density of *T. castaneum* reared on soft and hard wheat varieties. The results showed that, at low densities, the insects in the soft wheat flour produced about 15 times the progeny of those fed on the hard wheat flour and developed significantly faster. He therefore concluded that there was an interaction between the physical food quality and the population development of *T. castaneum*.

Table (9):

Proximate chemical composition of the four cereal flours

Flour	Moisture (%)	Ash (%)	Oil (%)	Protein (%)	Carbohydrates (%)
Wheat	6.41 (a)	2.30 (a)	4.10 (b)	13.89 (a)	73.30 (c)
Millet	5.90 (a)	2.40 (a)	5.46 (a)	12.87 (a)	73.37 (c)
Sorghum	6.25 (a)	2.42 (a)	3.68 (b)	10.15 (b)	77.50 (b)
Rice	5.99 (a)	1.07 (b)	2.30 (c)	8.10 (c)	82.54 (a)
S.E (±)	0.154^{NS}	0.178^{**}	0.306^{**}	0.599^{**}	0.912^{**}

* = Significant differences at 5% level.

** = Significant differences at 1% level.

NS = Not significant.

- Values are means (±) S.E
- Means not sharing a common subscript letter in a column are significantly different at $P \leq 0.05$ as assessed by Duncan's multiple range test.

4.6. Conclusion

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

1. The total developmental period of *T. castaneum* reared on sorghum flour varied considerably according to the prevailing environmental conditions particularly temperature;
2. Food type (different cereal flours) had significant effect on the total developmental period of the red flour beetle which indicates its suitability. Millet flour was the most favourable and rice was the least favourable for the development of the different stages of the beetle;
3. Different cereals flours used as food for *T. castaneum* had significant effect on the mean body weight of the different stages. The mean weight was less for insects reared on rice flour than for those reared on wheat flour;
4. Since sex ratio of *T. castaneum* was close to unity on sorghum flour, greater than unity on both millet and wheat flours and less than unity on rice flour with the predomination of males, this can explain the higher population increase in millet and wheat compared to that of rice flour;
5. As the rice flour showed the lowest level of total percentage of weight loss and lowest total adult population and wheat and millet flour showed the highest levels, thus the former are considered as the least susceptible to infestation, while the latter were the most susceptible;
6. The low amounts of ash, oil and proteins in rice flour compared to other flours can explain why *T. castaneum* was not able to develop and multiply faster on this flour; and finally as a general conclusion,

7. The findings show the importance of this pest, on flours of wheat, millet, and sorghum and that rice appeared to be the least susceptible. Wheat and millet flours are the most vulnerable to infestation.

4.7. Recommendations:

1. When considering *T. castaneum* management on stored flours, more attention and concentration should be directed towards those of cereals, with wheat, millet and sorghum flours deserving the utmost care due to their highest vulnerability to infestation.
2. Further investigations may be required to elucidate the effect of the different types of flours (food) on the sex-ratio of *T. castaneum* and on enhancement of development and multiplication of this pest.

REFERENCES

A. A. Abdalla, A. H.. El Tinay, B. E. Mohamed (1997). Effect of traditional processes on phytate and mineral content of pearl millet. Department of Biochemistery, Faculty of Agriculture, University of Khartoum, Shambat, Sudan. Food chemistry, vol. 63, No. 1, pp. 79 - 84

Abdelsamad, R.M. (1985). Studies on phenology and bionomics of *Tribolium castaneum* Herbst., in Gezira, Sudan. M.Sc. Thesis, University of Gezira.

Abdel shakour, O.M. (1987). A summary information on problems due to pests on stored agricultural materials in Port Sudan. In: Workshop on *Storage and preservation of food grains*, Friendship Hall, Khartoum, 1987.

*Abu shama, F.T.; Al-Jeraiwi-J; Jeriwi-J-Al- (1987). Food preference and development of the red flour beetle *Tribolium castaneum* Herbst. *Journal -of – the University of Kuwait, Science*. 1987, 14 (1): 161 – 173

Adams, J.M. (1977). A review of literature concerning losses in stored cereals and pulses. *Journal of tropical Science* 19 (1): 1 – 28.

Adesuyi, S.A. (1993). Comparative assessment of grain structure in Nigeria and some countries in Africa and Asia. *Agricultural Mechanization in Asia, Africa and Latin America*. 24(2): 69 – 75.

Anonymous, (1986). Identification and biology of storage insects and mite a (*training manual)*. Natural Resources Institute (N.R.I) Chathum, London U.K.

AOAC (1984). Official methods of analysis of the association of official analytical chemist. *AOAC.* Washington, D.C. USA. (955pp).

Audery D. Aitken (1975). Insect Travellers, Biology of *Tribolium castaneum* (*technical Bulletin* - Insect Travelers). 31 (1): 157 – 158.

Bains, S.S. (1971). Effect of temperature and moisture on the biology of *Rhizopertha dominica* F., *Bull. Grain Tech*. (9): 197 – 202.

Bailey, J. E. (1992). Whole grain storage. In: *storage of cereal grains and their products*. (Editor: Sauer, D.B.). Fourth edition. American Association of cereal chemists, Minnesota USA.

Basumia, M.A., Abe, T. and Bala, B.K. (1996). Application finite element methods for the simulation of temperature distribution during storage of rough rice in cylindrical bin. *Agricultural mechanization in Asia, Africa and Latin America*. 27 (2): 33 – 40.

*Bekon – KA, Lessard – F.F. (1988). Olfactory and alimentary discrimination between cereal grains of six species in adults of *Tribolium castaneum* Herbst., *Acta – oecologica, oecologia- Applicata*. 9 (2): 153 – 171.

Bell, C.H. and Armitage, D.M. (1992). Alternative storage practices. In: *storage of cereal grains and their products*. (Editor: Sauer, D.B.). Fourth edition. American Association of cereal chemists, Minnesta. USA.

*Bhatia – P, Sethi- G.R. (1989). Studies on the nutritional variables in *Tribolium castaneum* Herbst., reared on different varieties of Bengal gram, *Cicer arietinum* Linn. *Indian-Journal of Entomology*. 51 (1): 29 – 38.

Birch, L.C., Park, T. and Frank, M.B. (1954). The effect of intraspecies and interspecies competition on the fecundity of two species of flour beetles. Evolution, 5: 116 – 132.

Bond, E.J. (1980). Sorption of tritiated phosphine by various stages of *Tribolium castaneum* Herbst., *Journal of stored production Research*. 16: 27 – 31.

Boxall, R.A. (1974). Underground storage of grain in Harar Province, Ethiopia. *Trop. Stored Prod. Inf*. 28: 39 – 48

Boxall, R. A., La Gra, J. Martinez, E. and Martinez, J. (1981). Post harvest losses of rice in the Dominica Republic. *Trop. Stored Prod. Inf.* 42: 5 – 10.

Breese, M.H. (1963). Studies on the oviposition of *Rhizopertha dominica* F., in rice and paddy. *Bull. Ent. Res*. 53: 621 – 637.

Brooker, D.B., Bakker – Arkema, F.W. and Hall, C.W. (1981) *Drying cereal grains*. Avi Publishing Company. West Port. Connecticut. USA.

Christensen, C.M. and Kaufmann, H.H. (1969). *Grain storage*. University of Minnesota Press. Minneopolis. Minnesota. USA.

Dalel, S.K. and Gupta, D.S. (1974). Relative resistance of some verities of wheat to *Sitophilus oryzae* L. and *Rhizopertha dominica* F., at different temperature. *Bull. Grain Tech*. 12: 117 – 124.

Darling, H.S. (1959). The insect pests of stored grain in the Sudan, with special reference to the factors affecting the incidence of infestation. Ph.D Thesis, University of London.

Dawson, P.S. (1977). Life- history strategy and evaluationary history of *Tribolium* flour beetles (*Evolution*) 31 (4): 226 – 229.

*Dayakar, S. Ray – SN. (1998). Effect of physical barrier on growth and development of *Tribolium castaneum* Herbst., on wheat. *Insect Environment*. 4 (1): 9.

Doraiswamy, V., Subramariam, T.R. and Dakshina murthy, A. (1976). Varietal preference in sorghum for the weevil *sitophilus oryzoe* L., *Bull. Grain Tech*. 14: 107 – 111.

Drich, B.C. and Pran, V. (1987). Nutritional evaluation of some varieties of sorghum. *Cereal chemistery* 64: 413 – 417.

Elagib, S.M.A. (1987). Observation on grains storage in traditional and modern vessels in Sudan. Workshop on *storage and preservation on food grains*. Khartoum. Sudan

EL Hag A.M. (1992). Study on some aspects of susceptibility of sorghum grain varieties to stored product insects. M.Sc. Thesis, University of Gezira.

EL Khidir, E. (1982). A survey of grain storage practices and losses in the Sudan. *National grain storage seminar*, Khartoum, Sudan.

Erakay, S. and Ozar, A.I. (1978). Investigations in the Aegean region on the effects of methyl bromide fumigation against some stored products pests under different conditions. (*Bilk, Koruma Butteni*,) 18: 32 – 37.

FAO. (1983). Post-harvest losses in quality of food grains. Food and nutrition paper 29. FAO. Rome. Italy.

Frank, K. HO. (1960). Discrimination between the pupa of *Tribolium confusum* Duv., and *Tribolium castaneum* Herbst. *Ann. Entomol. Soc. Amer*., 53: 280 – 281.

Frank, K. HO. (1967). Identification of *Tribolium* larvae by their setal characteristics (Coleoptera: Tenebrionidae). *Ann. Entomol. Soc. Amer*., 60: 729 – 732.

Gomez, K. A. and Gomez, A.A. (1984). *Statistical procedures for agricultural research*. Second edition. John Wiley and Sons. Singapore. (294 pp).

Good, N.E. (1933). Biology of the flour beetles *Tribolium confusum* Duv., and *Tribolium ferrugineum* Fab., *J. Agric. Res*. 327 – 334.

Good, N. E. (1936). The flour beetle of the genus *Tribolium*. *Tech. Bull*. U.S. Dep. Agric. No. 498. (57 pp.).

Guddoura, E. and Medani, H.M. (1987). The role of plant protection in the control of stored – products pests. Workshop on *storage and preservation on food grains*. Khartoum. Sudan.

Hall, D.W. (1963). Some essential considerations on the storage of food grains in tropical Africa. (*Information working Bull*). 24: 74 – 75.

Hall, D.W. (1970). *Handling and storage of food grains in tropics and subtropics areas*. FAO. Rome. Italy.

Hall, D.W. (1983). *Handling and storage of food grains in tropical and subtropical areas*, edition No. (2). Agricultural department paper 90. FAO Rome. Printed in the United Kingdom.

Halstead, H.G.D. (1963). External Sex differences in stored products coleopteran. *Bull. Ent. Res*., 54: 119 – 134.

Harein, P.K. and Davis, R. (1992). Control of stored – grain insects. In: *storage of cereal grains and their products*. Editor: Sauer, D.B. Fourth edition. American Association of cereal chemists, Minnesota. USA.

Hassan, A.M. (1987). A study on malathion resistance in *Tribolium castaneum* Herbst,. In: Workshop on *Storage and preservation of food grains*. Friendship Hall, Khartoum, (1987).

*Hassan, M., Khan – AR. (1988). Growth and development of the red flour beetle, *Tribolium castaneum* Herbst., on red lentil flour, *Lens esculenta*. *Bangladesh – journal – of zoology*. 16 (2): 177 – 180.

Hem Singh Prutli and Mohansingh, (1950). Pests of stored grain and their control. Issued by *Indian Council of Agricultural Research*.

Howe, R.W. (1956). The effect of temperature and humidity on the rate of development and mortality of *Tribolium castaneum* Herbst., *Ann. Appl. Biol*., 44: 356 – 368.

Howe, R.W. (1962). The effect of temperature and humidity on the oviposition rate of *Tribolium castaneum* (Herbst) (Coleopteran. Tehebrionidae) *Bull. Ent.* Res., 53: 301 – 310.

*Imura, O. (1991). A comparative study of the feeding habits of *Tribolium freemani* Hinton and *Tribolium castaneum* Herbst., *Applied – Entomology – and – Zoology*. 26(2): 173 – 182.

Iqbal, M., Younis, M. Sabir, M.S. and Qumar, S.A. (1996). Design and development of continuous – flow rotary grain dryer. *Agricultural Mechanization in Asia, Africa and Latin America*. 27 (2): 41 – 45.

Itto, A. (1987). Report on Survey of Local storage systems and their pests in the Southern Regions of the Sudan. Workshop on *storage and preservation on food grains*. Khartoum. Sudan.

Karan, S., Agrawal, N.S. and Girish, G.K. (1973). Studies on the population of *Sitophilus oryzae* L., in high yielding varieties of wheat under different ecological conditions. *Bull. Grain Tech*. 11: 50 – 58.

Khalifa, A. and Badawy, A. (1955a). The effect of nutrition on the biology of *Tribolium confusum* Duv., *Tribolium castaneum* Herbst., and *Latheticus oryzae* Waterh., *Bull. Soc. Entomol. Egyp*t. 39: 337 – 350.

Khalifa, A. and Badawy, A. (1955b). Biological Studies on *Tribolium confusum* Duv., *Tribolium castaneum* Herbst., and *Latheticus oryzae Waterh*., *Bull. Soc. Entomol. Egypt* 39: 351 – 373.

Khalifa, A. (1960). Open – air and underground storage in the Sudan. Bull. Ent. Soc. Egypt, 44: 129 – 142.

Khalil, A.R. (1970). Pests of stored products in the Sudan. Department of Crop Protection. Ministry of Agriculture.

Khalil, A.R. (1975). Estimation of losses in stored agricultural products at Port Sudan. Plant Protection Administration. *Bulletin*. No 2.

Krishnamurthy, K., Medani, H.H. and EL Zaki, M. (1987). Study on storage and pest management practices of Dura handled by Agricultural Bank of Sudan. In: Workshop on *Storage and preservation of food grains*. Friendship Hall, Khartoum, 1987.

Krishnamurthy, K., Medani, H.H. and EL Zaki, M. (1989). *Manual on storage and food grains*. FAO – GCP/SUD/035/AUL – PPD Wad Medani, Sudan.

Laoata, T.E.B. (2001). Insect Pests Populations: sampling and Statistical Methods. Azza Publishing House, Khartoum. 398 pp. (In Arabic)

Lecato, G.L. (1975). Red flour beetle: population growth on diet of corn, wheat, rice or shelled peanuts supplemented with eggs or adults of the Indian meal moth. *J. Econ. Entomol*., 68: 763 – 765.

Leonard, M., Redlnger, Larry, J. and Simonaitis, R. (1982). Evaluation of pirimiphos-methyl- as protectant for export grain. *J of stored Prod. Res*. 11 (2): 65 – 70.

Lindgren, D.L. and Vincent, L.E. (1966). Relative toxicity of hydrogen phosphide to various stored product insects. J. *stored Prod*. *Res*. 2: 41 – 46.

*Longstaff, B.C. (1995). An experimental study of the influence of food quality and population density on the demography performance of *Tribolium castaneum* Herbst., *Journal of stored products Research*. 31 (2): 123 – 129.

Mahmoud, A.M. (2001). Research on grain production dictated by the requirements of the local and international market. In: *country symposium on the development and improvement of the efficiency of cereals marketing systems in Sudan*. Sudan Agric. Bank and FAO, Khartoum, Sudan.

Mc Farlane, J.A. (1970). Insect control by airtight storage in small containers. *Tropical stored products information* 19: 10 – 14.

Mc Ganghey, W.H. (1976). *Bacillus thuringiensis* for controlling three species of moths in *stored grains.Canadian Entomologist* 108: 105 – 112.

Mc. Gregor, H.E. (1964). Preference of *Tribolium castaneum* for wheat containing various percentage of dokage. *J. Econ. Entomol.* 57: 511 – 513.

Ministry of Agriculture and Natural Resources (2001). The series of the main food and oil crops (1970 / 1971 – 1998/ 1999). No. 4 (Amal Mustafa Maragan).

More, H. G., Stenning, B.C. and Magan, N. (1992). Effect of high temperature treatment on disinfestations and quality characterstics of sorghum. *Annals of Applied Biology*. 120 (1): 161 – 171.

Mustafa, M.F. (1983). Studies on infestation of different sorghum varieties in different types of stores and their control. M.Sc. thesis University of Khartoum, Sudan.

Nigam, B.S. (1966). Bionomics of stored grain pests. *Labder J. Tech*. 4: 168 – 173.

Pederson, J.R. (1992). Insects In: *Storage of cereal grains and their products* (Editor: Association of cereal chemists, Minnesota. USA.

Phadka, K.G. and Bhatia, S.K. (1974). Population growth of *Sitophilus oryzae* L., and *Rhyzopertha dominica* F., in wheat varieties. *Indian J. Entomol*. 36: 251 – 260.

Phillips, J.K. and Burkholder, W.E. (1985). Health hazards of insects and mites in food. In: *insect management for storage and processing* Editor: Bau, F.J. Second edition. American Association of cereal chemists, Minnesota. USA.

Pomeranz, Y. (1992). Biochemical, functional and nutritive changes during storage. In: *storage of cereal grains and their products*. Editor: Sauer, D.B. Fourth edition. American Association of cereal chemists, Ministry. USA.

Prevett, P.F. (1975). Stored – product pests causing losses of stored food. *FAO Plant Production Bulletin* 23 (3): 115 – 117.

Robert, E.P. (1985). Fundamentals of Applied Entomology. Macmillan Publishing Company, USA.

Russell, P.M. (1966). Effects of four sorghum varieties on longevity of the lesser rice weevil *Sitophilus oryzae* L., *J. Stored Prod. Res*. 2: 75 – 79.

Saad, A.A. (1978). Pests of stored grain in the Sudan. Syposium paper on *crop pest management*, Khartoum, Sudan.

Saad, A.A. and Guddoura, E. (1982). The role of the plant protection in the control of pests of stored grains. *National grain storage* seminar. Khartoum, Sudan.

Samuel, C.K. and Chetterji, S. (1953). Studies on the varietal resistance and susceptibility of Jowar (Andropogon sorghum) to storage pest in India *Res. App. Entomol. A*. (43): 152.

*Sattigi, H. N, Kulkarni, K.A., Lingappa, S. (1995). Biology of red flour beetle, *Tribolium castaneum* Herbst., on different cereal flours under laboratory conditions. *Karnataka, Journal of Agricultural Sciences*. 1995, 8 (1): 86 – 89.

Seif Elnasr, Y.E. and Mills, R.B. (1985). Resistance of pearl millet cultivars to *Sitophilus oryzae*, *Sitotroga cerealella* and *Rhizopertha dominica*. Trop. Sci 78: 181 – 184.

Seif Elnasr, Y.E. (1992). Stored grain insects found in sorghum stored in the central belt of Sudan and losses incurred. *Trop. Sci*. 32 (3): 223 – 230.

Shazali, M.E.H. (1977). Susceptibility of Dura to *Tribolium spp*. *Ann. Rep. Kenana Res. Stn*.

Shazali, M.E.H. (1982). The biology and population ecology of four insect pests of stored sorghum with particular reference to competition and succession. PH.D. thesis, University of Reading, U.K.

Shazali, M.E.H. (1987). Problems of food grain storage in the Sudan with particular reference to insects. Workshop on *storage and preservation on food grains*. Khartoum, Sudan.

Shazali, M.E.H. and Smith, R.H. (1990). The growth of single and mixed laboratory populations of three insects pests in stored sorghum. *Bull. Of grain Technology*, 28 (2): 107 – 112.

Shazali, M.E.H., EL Hadi, A.R. and Khalifa A.M.H. (1996). Storability of sorghum grain in traditional and improved matmora *J. Trop. Sci*. 36: 182 – 192.

Shazali, M.E.H. and Ahmed, M.A. (1998). Assessment and reduction of losses in sorghum stored in traditional mud bins in Sudan. *Journal of Tropical Science*. 38: 155 – 160

*Singh - R., Singh – S, Singh – K, Goel – Sc. (1992). Biology of *Tribolium castaneum* Herbst., in different flours. Bioecology and control of insect pests: Proceedings of the National symposium on *growth, Development and control Technology of insect pests*. 1992, 60 – 64.

Sinha, R.N. and Wallace, H.E.H. (1977). Storage stability of farm stored rape seed and barley. *Canadian Journal of Plant Science*. 57: 351 – 365.

Uiso, C.B.S., Gough, M.C. and Stiger, C.J. (1990). Detection, causes and consequences of convective currents in bulk-stored grain. *Netherlands Journal of Agricultural Science* 38 (2): 195 – 199.

White, G.G. (1982). The effect of grain damage on development of *Tribolium castaneum* Herbst., *J. Stored Prod. Res*. 18: 115-119.

*White, N.D.G., Loschiavo – S.R. (1988). Oviposition and larval development of the red flour beetle and the rusty grain beetle on ground and ball-milled kernels of various cereal cultivars. *Canadian Journal of Plant Science* 1988, 68 (3): 617 – 626.

Wigglesworth, V.B. (1950). The principles of insect physiology. London, published by Chapman and Hall.

William, F. Lyon (1991). Confused and Red flour Beetles. *Extension Fact sheet, Entomol*., Ohio State University.

Yinon, U. and Shalov, A. (1970). The dispersion of *Trogoderma granarium* EV., in a temperature gradient and comparison with other stored production beetles. *Ent. Exp. App*. 13: 107 – 121.

* = (Seen as abstract)

APPENDICES

Appendix 1.1. a.

Data on development of *T. castaneum* at laboratory conditions in Shambat (19 October / 2000)

Rep. No.	Date eggs laid	Date eggs hatched	Incub. Period (days)	Date of 1st molt	Du. Of 1st instar (days)	Date of 2nd molt	Du. Of 2nd instar days	Date of 3rd molt	Du. Of 3rd instar (days)	Date of 4th molt	Du. Of 4th instar (days)	Date of 5th molt	Du. Of 5th instar (days)	Date of pupation	Du. Of last instar (days)	Du. Of larval period (days)	Date of adult emerged	Du. Of pupal period (days)	Du. Of develop. period days
A	19/10	29/10	10	31/10	2	3/11	3	5/11	2	7/11	2	10/11	3	14/11	4	16	20/11	6	32
B	19/10	29/10	10	31/10	2	3/11	3	5/11	2	8/11	3	10/11	2	15/11	5	17	21/11	6	33
C	19/10	28/10	9	30/10	2	3/11	4	5/11	2	7/11	2	9/11	2	14/11	5	17	19/11	5	31
D	19/10	29/10	10	30/10	1	3/11	4	6/11	3	8/11	2	10/11	2	15/11	5	17	20/11	5	32
Mean			9.75		1.75		3.50		2.25		2.25		2.25		4.75	16.75		5.5	32

Appendix 1.1. b.

Data on development of *T. castaneum* at laboratory conditions in Shambat (24 October / 2000)

Rep. No.	Date eggs laid	Date eggs hatched	Incub. Period (days)	Date of 1st molt	Du. Of 1st instar (days)	Date of 2nd molt	Du. Of 2nd instar (days)	Date of 3rd molt	Du. Of 3rd instar (days)	Date of 4th molt	Du. Of 4th instar days	Date of 5th molt	Du. Of 5th instar days	Date of pupation	Du. Of last instar (days)	Du. Of larval period (days)	Date of adult emerged	Du. Of pupal period (days)	Length Of deve. period (days)
A	24/10	2/11	9	4/11	2	7/11	3	9/11	2	11/11	2	13/11	2	1811	5	16	23/11	5	30
B	24/10	3/11	10	5/11	2	9/11	4	1111	2	1311	2	1511	2	20/11	5	17	25/11	5	32
C	24/10	2/11	9	3/11	1	7/11	4	9/11	2	11/11	2	13/11	2	18/11	5	16	23/11	5	30
D	24/10	4/11	11	6/11	2	10/11	4	11/11	2	13/11	2	1511	2	19/11	4	16	23/11	4	31
Mean			9.75		1.75		3.75		2		2		2		4.75	16.25		4.75	30.75

Appendix 1.1. c.

Data on development of *T. castaneum* at laboratory conditions in Shambat (September /October 2001)

Rep. No.	Date eggs laid	Date eggs hatched	Incub. Period (days)	Date of 1st molt	Du. Of 1st instar (days)	Date of 2nd molt	Du. Of 2nd instar (days)	Date of 3rd molt	Du. Of 3rd instar (days)	Date of 4th molt	Du. Of 4th instar (days)	Date of 5th molt	Du. Of 5th instar (days)	Date of pupation	Du. Of last instar (days)	Du. Of larval period days	Date of adult emerged	Du. Of pupal period days	Du. Of devel. period days
A	21/9	1/10	10	3/10	2	7/10	4	9/10	2	11/10	2	14/10	3	1810	4	17	22/10	4	31
B	21/9	1/10	10	3/10	2	7/10	4	9/10	2	11/10	2	14/10	3	18/10	4	17	22/10	4	31
C	21/9	1/10	10	4/10	2	7/10	3	9/10	2	12/10	3	15/10	4	19/10	4	18	24/10	5	33
D	21/9	1/10	10	4/10	2	7/10	3	11/10	4	14/10	3	15/10	2	18/10	3	17	23/10	5	32
Mean			10		2		3. 5		2.5		2.5		3		3.75	17.25		4.5	31.75

Appendix 1.1. d.

Data on development of *T. castaneum* at laboratory conditions in Shambat (June/July 2002)

Rep. No.	Date eggs laid	Date eggs hatched	Incub. Period (days)	Date of 1st molt	Du. Of 1st instar (days)	Date of 2nd molt	Du. Of 2nd instar (days)	Date of 3rd molt	Du. Of 3rd instar (days)	Date of 4th molt	Du, Of 4th instar (days)	Date of 5th molt	Du. Of 5th instar (days)	Date of 6th molt	Date of pupation	Du. Of last instar (days)	Du. Of larval period (days)	Date of adult emerged	Du. Of pupal period (days)	Length Of deve. Period (days)
A	19/6	26/6	7	28/6	2	7/10	3	3/7	2	5/7	2	7/7	2	9/7	13/7	4	17	18/7	5	29
B	19/6	25/6	6	26/6	1	29/6	3	1/7	2	3/7	2	5/7	2	7/7	10/7	3	15	14/7	4	25
C	19/6	25/6	6	26/6	1	29/6	3	1/7	2	3/7	2	5/7	2	7/7	10/7	3	15	14/7	4	26
D	19/6	25/6	6	26/6	1	29/6	3	1/7	2	3/7	2	5/7	2	7/7	10/7	3	15	14/7	4	26
E	19/6	26/6	7	28/6	2	1/7	3	1/7	2	5/7	2	7/7	2	9/7	12/7	3	16	16/7	4	27
Mean			6.25		1.4		3		2		2		2			3.2	15.50		4.2	26.00

Appendix 1.2 Anova tables for life-cycle in sorghum flour

a- Incubation period in days

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	38.688	12.896	36.41	0.00	3.49
Within Groups	12	4.250	0.354			
Total	15	42.938				

b- Larval period in days

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	6.688	2.229	5.10	0.017	3.49
Within Groups	12	5.250	0.438			
Total	15	11.938				

c- Pupal period in days

Source of variation	Df	SS	MS	alc.F	p-value	Tab.F
Between Groups	3	3.500	.167	4.00	0.035	3.49
Within Groups	12	3.500	0.292			
Total	15	7.000				

d- Total development period in days

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	94.250	31.417	19.33	0.000	3.49
Within Groups	12	19.500	1.625			
Total	15	113.750				

Appendix 2.1 Anova tables for assessment Duration of development (days)

a- Egg incubation period in days

Source of variation	Df	SS	MS	Calc.F	Tab.F 5 %	Tab.F 1 %
Flours	3	17.480	5.827	71.032	2.87	4.38
Periods	3	853.918	284.639	3469.889	3.86	6.99
Periods × flour	9	7.379	.820	9.995	2.15	2.95
Error	48	3.938	8.203E-02			
Total	64	5481.250				

b-Larval period in days

Source of variation	Df	SS	MS	Calc.F	Tab.F 5 %	Tab.F 1 %
Flours	3	1187.38	395.79	151.078	2.87	4.38
Periods	3	696.66	232.22	88.640	3.86	6.99
Periods × flour	9	342.97	38.11	14.546	2.15	2.95
Error	48	125.750	2.620			
Total	64	39025.000				

c-Pupal period in days

Source of variation	Df	SS	MS	Calc.F	Tab.F 5 %	Tab.F 1 %
Flours	3	5.55	1.85	9.155	2.87	4.38
Periods	3	1.39	0.46	2.239	3.86	6.99
Periods × flour	9	3.42	0.348	1.723	2.15	2.95
Error	48	9.688	.202			
Total	64	1972.250				

d-Total development period in days

Source of variation	Df	SS	MS	Calc.F	Tab.F 5 %	Tab.F 1 %
Flours	3	1644.01	548.00	218.860	2.87	4.38
Periods	3	2703.36	901.12	359.885	3.86	6.99
Periods × flour	9	368.38	40.93	16.347	2.15	2.95
Error	48	120.188	2.504			
Total	64	96910.250				

Appendix 2.2 Anova tables for assessment weight of body (mg)

a-Larva mean wt.(mg)

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	6.977	2.326	23.87	0.00	2.76
Within Groups	60	5.847	0.097			
Total	63	12.824				

b-Pupa mean wt.(mg)

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	2.070	0.690	7.15	0.00	2.76
Within Groups	60	5.788	0.096			
Total	63	7.858				

c- Adult mean wt.(mg)

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	1.652	0.551	19.02	0.00	2.76
Within Groups	60	1.737	0.029			
Total	63	3.389				

Appendix 3. Anova tables

a. Weight loss (g)

Source of variation	Df	SS	MS	Calc.F	Tab.F 5 %	Tab.F 1 %
Flours	3	2887.51	962.50	7.767	2.96	4.60
Periods	2	6385.95	8192.97	66.115	5.14	10.92
Periods × flour	6	2321.42	386.904	3.122	2.46	3.56
Error	36	4461.121	123.920			
Total	48	89286.972				

b. Percent weight loss (%)

Source of variation	Df	SS	MS	Calc.F	Tab.F 5 %	Tab.F 1 %
Flours	3	722.00	240.67	7.769	2.96	4.60
Periods	2	4096.51	2048.25	66.115	5.14	10.92
Periods × flour	6	580.45	96.74	3.123	2.46	3.56
Error	36	1115.279	30.980			
Total	48	22325.793				

c. Number of live adults

Source of variation	Df	SS	MS	Calc.F	Tab.F 5 %	Tab.F 1 %
Flours	3	3044524.25	1014841.42	5.537	2.96	4.60
Periods	2	10306471.29	51532350.65	28.117	5.14	10.92
Periods × flour	6	1835119.88	305853.31	1.669	2.46	3.56
Error	36	6597904.5	183275.125			
Total	48	43737800.00				

Appendix 4. Anova tables for chemical analysis test

a- Moisture content (%)

Source of variation	Df	SS	MS	alc.F	p-value	Tab.F
Between Groups	3	0.487	0.162	2.27	0.157	4.07
Within Groups	8	0.572	0.071			
Total	11	1.059				

b- Ash content (%)

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	3.862	1.28632	13.39	0.002	4.07
Within Groups	8	0.775	0. 096			
Total	11	4.677				

c- Oil content (%)

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	15.457	5.0961	18.1417	0.011	4.07
Within Groups	8	5.582	0.28066			
Total	11	21.039				

d- Protein content (%)

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	63.173	21.058	19.56	0.000	4.07
Within Groups	8	8.614	1.077			
Total	11	71.787				

e- Carbohydrate content (%)

Source of variation	Df	SS	MS	Calc.F	p-value	Tab.F
Between Groups	3	192.10	57.915	25.65	0.001	4.07
Within Groups	8	19.90	2.49348			
Total	11	212.00				