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Studies on the effect of host type and textures on the survival of *Tribolium castaneum* (Coleoptera: Tenbrionidae) parental and filial generations.

By

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List of abbreviations

IGRS………Insect Growth Regulators

Spp.…..… ….Species

IPM……..Integrated Pest Management

ETs………Economic Threshold Levels

Abstract: The development of *Tribolium castaneum* (Herbst) was studied at two levels of grain breakage (10, 50%), milled (flour) and whole grain of 20 g different grains or hosts (maize, barely, wheat, sorghum, chick pea, faba bean, field pea and haricot bean) that were purchased from Markato. These 10 and 50% broken, whole flour, and whole grain (control) were kept in an oven at 40 C for four hours to disinfest from internal infestation. Then 20 g of each of the four distinct textures (including the control) of the grains were put in 32 one liter capacity glass jars each and adults (seven pairs), 1-3 days old *T. castaneum* were introduced in each jar containing 20 g of each of the three distinct textures of the grains. Following this, the different textures of the grains in each of the 32 glass jars were kept under laboratory condition (27±2 ºC and 60-65% relative humidity) and female beetles were allowed to lay eggs for 20 days after which all dead or live insects were removed. Thereafter, the treatments were left and checked daily until larva, pupa and adult emergence respectively. Larvae, pupae and adults' emergence was recorded subsequently 12, 5 and 20 days in succession after the first larva, pupa and adult emergence in each treatment and replicate. The experiment was set up in a completely randomized design in three replications in Addis Ababa university of Ethiopia for two generations. The result obtained indicated that adults' survival and progenies development of *T. castaneum* in whole and broken grains derived from eight local hosts or grains mentioned above were varied. Survival of parental adult beetles was significantly lower ($P < 0.05$) in whole than in broken grains and flour in all cereal grains. Significantly ($P < 0.05$) higher mean number of Larva, pupa and adult progenies emergence of *T. castaneum* was recorded in whole milled cereal grains than in whole grains of cereals and in both the control and all other forms of pulses (Chick Pea, Faba Bean, Field Pea and Haricot Bean) both in the 1st and 2nd generations. Significantly ($P < 0.05$) higher number of *T. castaneum* larvae, pupae and adults progenies were recorded in whole milled, 50% and 10% grain breakage of cereal grains, respectively than in whole grain (the control) of cereals and in both the control and all other forms of pulses. Besides, significantly less ($P < 0.05$) number of *T. castaneum* larvae, pupae and adults progenies were recorded in almost all forms of pulses than in all forms of the cereal grains, except the control. The results also showed that in damaged cereal grains more larvae, pupae and adults progenies were emerged during the first generation than in the second. Moreover, significantly less ($P < 0.05$) number of larvae, pupae and adults were emerged in whole grains in the 1st and 2nd generations when compared with the number of larvae, pupae and adults developed in broken and milled grains of cereals.

1. INTRODUCTION

Most agricultural commodities are produced seasonally and their harvesting is normally done during a short period of three to five months, while their consumption is throughout the year. For this reason, storage becomes necessary and it is normally done for extended periods of more than six months in order to maintain a uniform supply of food for consumption, for the domestic and export market and to provide a buffer stock for contingencies such as drought, floods and war (http://fastonline.org browsed on 08 /09/2010).

Stored products include any materials, which may be dried, rendering them storable for future use as foodstuffs, industrial raw materials, medicines, or as planting materials and these include cereals, pulses, dried seeds and root crops (Chomchalow, 2003).

The composition and behavior characteristics (internal forces) of food grains vary, and grains are constantly being exposed to external forces including physical factors such as temperature and humidity; chemical factors such as oxygen supply; biological agencies such as bacteria, fungi, insects, rodents and man with his methods of handling, storing, transporting and disinfesting products (Hall, 1970). Among these, biological factors affect more than all others and among biological factors, insects are the pioneers which switch on the destruction of stored produce and behave as the precursors for microbial infection. The damage due to the late effects (caused by microbes) is more dangerous than the initial loss (by insects) (Kiruba, 2008).

Stored food, including grain, cereals, cereal products, dried fruit food, nuts, spices, drugs and many others are liable to be infested by large number of insects, most of which are cosmopolitan in distribution (El-Kashlan *et al*., 1995). The contamination of food grains due to immature stages of the insects, moulted skin, excreta, dead insects, reduction in nutrient of grains, germination reduction, secondary infection by microbes, discoloration, unacceptable odour are some of the problems associated with infested grains which make the food undesirable and also unhygienic (Kiruba, 2008).

According to Metcalf (1962) the pests of stored products are the most dangerous of all insects, because they feed up on products that have been grown, harvested, sometimes manufactured and stored.

The sources of pests attacking stored products include cross infestation (the infestation of one commodity by movement of insects and mites from another commodity), residual infestation (results from attack by insects which have remained in the structure of the store, vessel or vehicle after the removal of a previously infested commodity), infestation by flight and crawling of insects (All moths and many beetles move to stored products by flight and some species like *Tribolium castaneum* and *Tribolium Confusum* also crawl into new uninfected stored products) and natural source of infestation (arise from natural sources including nests of birds, rodents, spiders and insects (http://www.fao.org/docrep/ on 12/09/2009).

Two major groups of insects harbour the mostly economically important post-harvest products include Coleoptera (beetles) and Lepidoptera (moths and butterflies) and several Coleopteran and Lepidopteran species attack crops both in the field and in store. Crop damage by Lepidoptera is only done by the larvae and several Lepidopteran larvae entangle the feeding media through silky secretion which turns products into entwined lumps but, in the case of Coleoptera, both larvae and adults often feed on the crop and the two stages are responsible for the damage (http://www.fao.org/inpho/ browsed on 12/09/2009). The beetles comprise the largest natural order in the animal Kingdom with a total of no less than 300,000 described species, of which more than 600 have been associated with stored food products throughout the world. Some, through the agency and dispersal by man in international trade have attained cosmopolitan distribution and constitute the major cereal pests that attack stored cereals and grain legumes (http: //www.fao.org/doc. browsed on 08 /09/2010). Lepidoptera associated with stored products are all moths and one species the Angoumois grain moth, *Sitotroga cerealella* is capable of destroying sound, unbroken grain kernels, but most infest broken or damaged kernels or milled products (http://www.fao.org/docrep/, browsed on 12/09/2009).

Post-harvest insect pests could be categorized broadly as primary and secondary pests. Primary pests are those insects which can able to attack intact grains (*Sitophilus spp*. *S. cerelealla* and others) where as secondary pests are pests that can only attack the already damaged grains or grain products (*Tribolium* spp., *Polodia interpunctella*, *Ephestia* spp. and others) (Emana Getu, 1993). In other word, primary pests are those that are capable of penetrating and infesting intact kernels of grain, and have immature stages that can readily develop within a kernel of grain where as, secondary pests cannot infest sound grain, but feed on broken kernels, debris, higher moisture weed seeds, and grain damaged by primary insect pests and immature stages of these species are found external to the grain (Davey, 1965). It is often thought that secondary invaders cannot initiate an infestation, which is not true as in almost any storage situation there will be adequate amounts of broken grains and debris to support an infestation by secondary invaders and secondary invaders also contribute directly to grain spoilage after establishment, just as primary pests do (Weaver and Petroff, 2005).

These secondary invaders include confused flour beetle, *T. confusum* (Tenebrionidae), red flour beetle, *T. castaneum* (Tenebrionidae), Yellow mealworm, *Tenebrio molitor* L., Flat grain beetle, *Cryptolestes pusillus*) (Cucujidae), Siamese grain beetle, *Lophocateres pusillus* (Trogositidae), Broad nosed grain weevil, *Caulophilus oryzae* (Curculionidae), Mediterranean flour moth, *Anagasta kuehniella* (Zeller) (= *Ephestia*) (Pyralidae), Indian meal moth, *Plodia interpunctella* (Pyralidae) and Spider beetles (Ebeling, 2002).

Because food is susceptible to attack along the entire processing and marketing chain, pests must be controlled in diverse storage environments, including on-farm product storage, warehouses, food processing facilities, packinghouses, and retail outlets (Johnson, 2002). Overall, biotechnical, biological, cultural and chemical methods are crucial approaches for successful control of the most dominant stored product pests in general (Gwinner *et al*., 1990).

Stored grain is not an inert substance, but a respiring, living organic entity which deteriorates during storage, either quantitatively by the amount of dry matter lost (DML), or qualitatively by discoloration, mould contamination, sprouting and caking, etc., promulgated by the activity of microorganisms, invertebrate (insects and arachnids) and vertebrate pests (rodents and birds) and further weight losses are incurred during the handling transporting and processing of stored food commodities (http://www.fao.org/docrep/, browsed on 12/09/2009).

These losses of grain in storage due to insects can exceed those incurred while growing the crop and it includes not only the direct consumption of kernels, but also involves accumulations of frass, exuviae, webbing, and insect cadavers. High levels of this insect detritus may result in grain that is unfit for human consumption and insect-induced changes in the storage environment may cause warm, moist hotspots that are suitable for the development of storage fungi that cause further losses (Weaver and Petroff, 2005).

Worldwide losses in stored products, caused by insects, have been estimated to be between five and ten percent (Nakakita, 1998). Heavier losses occurring in the tropics may reach 30% and the net value of losses in storage in the United States has been placed at over $200 million annually (Weaver and Petroff, 2005). Such loss may reach up to 40%, in countries where modern storage technologies have not been introduced (Shaaya, 1997). These and other factors mentioned above are evidences that indicate the relevance of both primary and secondary insect pests as pests of stored products. Therefore, there is a need to understand the basic aspects of primary and secondary pests which include: their type, description, life cycle, economic- importance (their status) and the like. Hence, the current investigation was initiated with the following objectives:

2. OBJECTIVE

2.1. General objective:

- To understand the pest status of *Ttribolium castneum* on different hosts.

2.2. Specific objectives

- ü To determine the effect of different hosts in different forms to some biological Parameters of *Tribolium castaneum*.
- ü To determine appropriate hosts of *Tribloium Castaneum* from grains of local market under lab. condition.
- ü To determine the appropriate host textures of *Tribolium Castaneum*.

3. LITERATURE REVIEW

3.1. Post-harvest loss due to insect pests

Storage is one part of the post-harvest system through which food material passes on its way from field to consumer (Padin *et al.*, 2002). Losses occurring in this postharvest system are finite and unlike growing crop losses they cannot be made up by further plant growth and are affected by conditions prevailing in the pre-storage stages (harvesting, threshing and drying) and by conditions during storage (http://fastonline.org browsed on 08 /09/2010).

Stored product insect pests are a problem throughout the world, because they reduce the quantity and quality of grain. The reasons for their widespread presence range from evolutionary adaptations (morphological, physiological and behavioral) to the actions of humans who transport them throughout the world and offer a protected habitat (Pugazhvendan *et al.*, 2009).

In general, largely as a result of their ability for rapid population increase, the greatest damage to stored grains is caused by insect pests and over 750,000 known species of insects, only around 100 species have been found on stored produce and of these, only 20 species are of major importance with worldwide distribution (Mutambuki and Harberd, 2004).

Insect pest damage to stored grains is known to cause major economic losses to warehouse keepers, the milling industry and small scale farmers throughout the world and this problem is the greatest in developing countries (Ko Ko *et al*., 2009).

In tropical countries, the climate and storage conditions are favorable for insect growth and development (Talukder and Howse, 1995). More than 2000 species of field and storage pests annually destroy approximately one third of world's food production, valued US $ 100 billion among which highest losses (43% of potential production) occur in developing Asian countries (Ahmed and Grainge, 1986)

The loss of insect pests to stored grains and grain products may amount to 5–10% in the temperate zone and 20–30% in the tropical zone (Nakakita, 1998). Such loss may reach up to

40%, in countries where modern storage technologies have not been introduced (Shaaya, 1997). For example, in Sub-Saharan Africa, food grain losses during storage at farm level can reach as high as 25-40% (Dichter, 1976). Such high levels of food grain losses generally result from inadequate post-harvest management practices and poorly designed storage structures. It occurs at different point (harvesting, drying, threshing, winnowing, transportation and storage) (Harris and Lindblad, 1978).

However, there is no accurate data that quantify loss in Ethiopia. Some studies suggest that crop loss of 2 to 3%, 1 to 2%, 4 to 6%, 2 to 5% and 1 to 3% occur in cereals during cutting, drying, threshing, winnowing and transportation respectively (Anon, 1993). Losses of 25 to 50% in traditional farm storages and occational 100% losses in under ground pit storages were reported in the 1950s and1960s (Boxall, 1974). He estimated storage loss of food grain in Ethiopia due to insect pests and grain mold to be about 9%. In most literature, post harvest are quoted as 15%, but there has never been an organized post harvest crop loss assessment carried out in major food and cash crops nation wide (Abraham *et al*., 2008). Some reports estimated crop loss at about 2 to 4% and 5% due to insect pests at high and low altitudes respectively, and about 3% due to rodents at high altitudes, while grain moulds some times result in whole spoilage of grain stored in under ground pits (Anon, 1993).

This loss of stored products can be direct loss (reduction or loss in weight and reduction or loss of seed viability) or indirect loss (quality loss (i.e. nutrient loss, contamination, tainting or discoloration, Production of off-flavors and odors), monetary loss and Loss of good will) (http://fast online.org browsed on 08 /09/2010).

3.2. Biology and significance of *Tribolium* spp.

Life history of *Tribolium* species: flour beetles of the genus *Tribolium* and related genera of the family Tenebrionidae include the red flour beetle, *T. castaneum* and the confused flour beetle, *T. confusum* two major pests of stored grain products (Champ and Dyte, 1976). These *Tribolium* spp. can be major pests in structures used for the processing and storage of grain-based products (e.g., flourmills, warehouses, retail stores) (Campbell and Runnion, 2003), constituting important primary and secondary pests in many cereal products (Arnaud *et al*., 2005). *Tribolium* spp. are holometabolous insects, displaying a complete metamorphosis life cycle, in which all four-life stages differ in appearance (Rees, 2004). The white, microscopic eggs are laid amongst the infested commodity, and secrete a substance that provides them with a rather sticky outer membrane, allowing fine particles, such as flour to cling to their surfaces and this property conveniently provides a degree of camouflage, as well as permitting their adherence to surfaces or other packaging materials, throughout the egg life stage (Alabi *et al*., 2008). Upon hatching, the larvae immediately move in search of food and their small size readily allows them access to finished products and other packaged materials, which are often major weak links for an impending insect invasion (Conner and Via, 1992). These slender, wiry, mobile larvae appear a yellow-brown color, living and feeding directly within the infested commodity (Ebeling, 2002). Each individual can display as many as 5-12 larval instars (Walter, 1990); however, 7-8 are most common (Haines, 1991). This instar variation often tends to be a result of the environment, food (availability and quality), temperature, humidity, or due to other pressures exerted on the individual insect (Howe, 1956). The pupae are whitish, immobile, unprotected, non-feeding and therefore cause less overall product damage (Weston and Rattlingourd, 2000).

Tribolium spp. adults are reddish-brown, ranging from 3 to 4 mm long and live and feed in the infested commodity (Walter, 1990). The adult *T. castaneum* and *T. confusum* have subtle morphological differences. The head of *T. castaneum* does not have a visible beak and the thorax that has slightly curved sides, which conceals the joint between the thorax and the abdomen. In contrast, *T. confusum* has a visible beak, and a less rounded thorax, which makes their bodies appear more parallel, and allowing for the joint between the thorax and the abdomen to be visible and distinct (Ryan *et al*., 1970). The antennae of *T. castaneum* end in a three-segmented club, whereas *T. confusum* antennae end is a 4-segmented club that gradually enlarges toward the top, but does not form a distinctive club (Bousquet, 1990; Walter, 1990).

Mixed populations of *T. castaneum* and *T. confusum* do not occur often, as the competition between the two species has been reported to be intense. However, when these mixed populations do occur, they tend to do so only at low densities, because as population densities increase, the level of competition also increases, often concluding with one of species dominating and out-competing the other (Ryan *et al*., 1970). Cannibalistic behavior has been observed in *Tribolium* populations, whereby eggs, early larvae, and pupae are consumed by the feeding adults (Via, 1999). Previous studies have reported nutritional benefits to the larvae from egg consumption, such that upon emergence into the adult stage, a significant increase in fecundity was observed (Mertz and Robertson, 1970). Cannibalism as observed within mixed-species of *Tribolium* spp. populations is a potent force in the regulation that mediates the interspecific competition between *T. castaneum* and *T. confusum* (Via, 1999).

Tribolium spp. can complete development within a wide range of temperatures and relative humidity (r.h.) conditions. Howe (1956) demonstrated that when beetles were reared between 20ºC and 37.5ºC, and at an r.h. greater than 70%, adult development could be achieved in as little as 19-20 days. Accordingly, *T. confusum* can develop in environments with r.h. as low as 10%, a level that is prohibitive for the development of most other stored product insect pests. Both, *T. castaneum and T. confusum* adult beetles are long-lived, often with life spans of more than three years (Walter, 1990). In isolation, male *T. castaneum* live for as long as 2.5 years, and male *T. confusum* for up to 3.5 years. However, in groups or populations, the life expectancy of adult *T. castaneum* is reduced to six months, while that of *T. confusum* is still somewhat longer (Skoloff, 1972).

Because *Tribolium* feed primarily externally on stored grains (i.e., secondary colonizers), they will often have a greater reproductive capacity than primary feeders, which increases their potential for both causing losses and damaging grain products (Weston and Rattlingourd, 2000). *Tribolium* spp. males become sexually mature two days post-eclosion, whereas, females become sexually mature within a few days after emergence. The adult females reach their maximum egg-laying capacity between five to ten days old, and can successfully mate as early as 3 hours post eclosion, however not begin laying eggs until almost four days later (Dawson, 1965). Their typically long adult lifespan, combined with the prolonged amount of time in which they are reproductively active, is suggested as a coping strategy, enabling them to effectively contend with fluctuating conditions during characteristic colonization over exploitation cycles (Fedina and Lewis, 2007), as would commonly be experienced in mills, food warehouses and other stored product facilities.

Many of *Tribolium* spp. life-history traits show considerable phenotypic plasticity in response to environmental variation. Varying temperature, r.h., or food quality has been shown to greatly influence flour beetle development and behavior (Sokoloff, 1974). *Tribolium* spp. populations exhibit density fluctuations that affect both their biotic and abiotic environments. As efficient colonizers, *Tribolium* spp. can often achieve a relatively high intrinsic population growth rate, fast maturation, rapid larval development, as well as rapid dispersal activity (Fedina and Lewis, 2008). The rate of oviposition can be influenced by a range of both internal and external factors, including environmental conditions (i.e., temperature or r.h.) (Howe, 1962), the type and quality of available food material (Good, 1936), as well as conditions of over crowding (Birch *et al*., 1951). Nutritional quality of the flour medium is of the utmost importance to *Tribolium* spp. population dynamics, such that any slight change to the immediate environment can cause a significant decrease in the oviposition rate (Fedina and Lewis, 2007).

Unlike many insects, the flour beetles subsist in an infested food resource that is shared by both the adult and the juvenile stages (Weston and Rattlingourd, 2000). *Tribolium* adults can survive, develop and reproduce under conditions that are not suitable for the development of other stored product insect pests, allowing high population densities to be easily built up (Hill, 1990). As the population density increases, the shared flour medium that *Tribolium* spp. stages occupy begins to lose its nutritional quality, often accumulating waste products and other ethyl- and methyl benzoquinones, produced by adults and released as defensive compounds (Sokoloff, 1974). This density dependence has also been shown to cause extended larval developmental times (Kotaki and fujii, 1995), increased pre adult mortality due to cannibalism by the active adult and larvae stages on the inactive egg and pupae stages (Alabi *et al*., 2008), and further induced dispersal (Ziegler, 1977). *Tribolium* spp. has been known to cause significant damage in a number of stored commodities, within many stored product industry environments. The ease of their adaptability to survive harsh environments as well as developmental conditions, combined with their high reproductive capability, allows these insect pests the potential to cause significant product damage in and around food storage facilities (Emana Getu and Assefa G. Amlak, 1998).

Damage caused by *Tribolium* spp: *Tribolium* spp. has been associated with stored food for more than 4000 years (Levinson and Levinson, 1985). They are considered serious cosmopolitan pests of stored grains worldwide (Fedina and Lewis, 2007). They attack stored grain products such as flour, cereals, meal, crackers, beans, spices, pasta, cake mix, dried pet food, dried flours, chocolate, nuts, and seeds (Mahroof *et al*., 2003). *Tribolium* spp. are worldwide insect pests of mills, food warehouses, retail stores, and urban homes (Rees, 2004), and are often disseminated worldwide through transported grains (Ryan *et al.*, 1970). *T. castaneum* generally resides in both grain stores and mills, whereas *T. confusum* is more often found only in milling settings (Rees, 2004). *Tribolium* spp. are often more difficult to kill than other stored product beetles, though the order of toxicity will often vary depending on the particular insecticide utilized (Arthur, 2008). Today, *Tribolium* spp. continues to rank as a serious pest, in many parts of the world, both in developed and developing countries (Bughio and Wilkins, 2004).

Stored product pests including *Tribolium* species are economically important and are responsible for millions of dollars of loss every year, causing both quantitative and qualitative losses. In many developing countries, the overall post-harvest losses of cereals and legumes averages at rates of nearly 10–15% (Neethirajana *et al*., 2007), or about $1.4 to $2.8 billion per year (USDA, 2006). Grain losses resulting from insect infestations of all postharvest product loses have a major economic impact on the food industry due to the costs associated with the treatment and monitoring, rejection and return of contaminated products, loss of consumer goodwill, and failure to pass inspection or meet regulations (Campbell and Arbogast, 2004). The methods currently in use to control *Tribolium* populations have proven to be necessary in preventing a contamination of food materials, primarily used for human consumption. These methods specifically address the issues of stored, handled or processed food materials, and aid in preventing revenue losses (Daglish, 2005).

Wheat milling is a particular major food industry with a very low tolerance of insect infestation and flour mills contain complex networks of storage bins, processing equipment, and machinery for moving grain and milled material (Campbell and Arbogast, 2004). Within a milling setting, grain spillages and other residues in machinery and empty silos can support these residual infestations of stored-product insects (Sinclair and White, 1980). Infestations can arise from within the supply chain, resulting in contaminated food products being shipped through the supply chain to the product manufacturer (Faustini, 2006). However, once all precautions have been taken to ensure the processing and packaging of insect-free food, the food processor has little control over subsequent post-harvest shipping and storage. In developed countries, total food costs are increased with infestations, because of the amount of food that is lost after incurring all costs of growing, harvesting, processing, packaging, shipping, warehousing and retailing (Highland, 1977). The situation is significantly magnified by the presence of insects in finished and packaged goods, which directly affects consumer confidence (Collins, 1998).

Both *T. castaneum and T. confusum* may be present in large numbers in damaged grain, but neither species is a primary feeder of sound (i.e., undamaged) grain. Flour beetles are often attracted to grain that has high moisture content and it is this preference in conjunction with their secretion of benzoquinones, which lead to persistent odors that often encourages mold growth in the infested commodities/products (Assie *et al*., 2007). *T. castaneum* in particular is known to utilize many different flour types (Sokoloff *et al.,* 1966). This polyphagy results from local adaptation to the most common flour resource, as opposed to an individually generalized resource use. In granaries or flour mills, *Tribolium* spp. may often be exposed to only one or two grain types; however, on occasion, mills may contain many types of grain, which then provides the opportunity for increased selection in a more spatially heterogeneous environment, perhaps leading to the evolution of a more generalized *Tribolium* species (Via and Conner, 1995). Because residual infestations can be the primary source of insects infesting stored grain, industry places a heavy emphasis on managing these populations through the adoption and use of good hygiene practices, which call for an elimination of food sources that allow grain insects to survive and reproduce (Daglish, 2005). Product contamination by whole insects, eggs, insect fragments, frass, and cast skins often occurs in *Tribolium* infested processing plants and warehouses (Baur, 1984). Federal laws strictly regulate the presence of insects in processing facilities, as well as the amount of insect fragments in processed goods sold to consumers, insect management remains an important tool used to uphold consumer confidence (Neethirajana *et al*., 2007). Therefore, either the need exists to improve upon current IPM techniques, by refining methods previously utilized, or through the investigation and development of new techniques that prove to be safer and more environmentally friendly, than those currently being utilized for general insect pest management purposes (Bell, 2000).

3.3. Significance distribution description and life cycle of *Tribolium castaneum*

Damage caused by *Tribolium castaneum*: the rust-red flour beetle, *T. castaneum*, is a major secondary pest of cereal grains and their products in storage (Haines, 1991). Cereal cultivars differ in susceptibility to *T. castaneum* and traditional threshing can result in grain breakage which leads to infestation (Appert, 1987). The method of milling can influence its vulnerability to *T. castaneum* (Lale *et al.*, 2000).

The red flour beetle, *T. castaneum* (Coleoptera: Tenebrionidae), along with confused flour beetle attack stored grain products such as flour, cereals, meal, crackers, beans, spices, pasta, cake mix, dried pet food, dried flowers, chocolate, nuts, seeds, and even dried museum specimens (Via 1999, Weston and Rattlingourd, 2000).

The red flour beetle, *T. castaneum* which has a long association with human stored food, can be a major pest in anthropogenic structures used for the processing and storage of grain-based products (e.g., flour mills, warehouses, retail stores) and causes substantial loss in storage because of its high reproductive potential (Pugazhvendan *et al* ., 2009).

The red flower beetle, *T. castaneum* (Coleoptera: Tenebrionidae) is a common and most destructive pest throughout the world (Pranoto *et al*., 1991). This pest has also been reported to attack the germ part (embryo portion) of the grain (Nikkon *et al*., 2009). Their presence in stored foods directly affects both the quantity and quality of the commodity (Mondal, 1994).

The red flour beetles have chewing mouthparts, but do not bite or sting. They may elicit an allergic response, but is not known to spread disease and does not feed on or damage the structure of a home or furniture (Baldwin and Fasulo, 2007). These beetles along with the saw-toothed grain beetles and Indian meal moths are considered to be the most important pests of stored foods in grocery stores and in the home (Ebeling, 2002).

T. castaneum may have originally occurred primarily in rotting logs and under tree bark feeding on plant and animal detritus, and on insect eggs and pupae (Sokoloff, 1974). These natural and anthropogenic landscapes are characterized by spatially and temporally patchy resources. The ability of this species to find and colonize patches of food and to persist on small amounts of food that accumulate *in refugia* contributes to its pest status (Campbell and Hagstrum, 2002).

The red flour beetle gets its common name from its coloration and its habit of infesting flour (Girma kebede, 2009). But, the confused flour beetle apparently received this name due to confusion over about its identity as it is so similar to the red flour beetle at first glance (Walter, 1990).

***Tribolium castaneum* as laboratory test insect:** neither *T. castaneum,* nor *T. confusum* can climb up the vertical surfaces of glass containers. Besides this, *T. confusum* adults cannot fly, their wings being nonfunctional, while the *T. castaneum* adults can fly, but seldom do. These features, plus the fact that they can be easily reared in large numbers, make the 2 flour beetles popular test insects in entomological laboratories (Ebeling, 2002).

Distribution of *Tribolium castaneum*: the rust red flour beetle, *T. castaneum,* is a series pest of stored cereals in tropical and sub-tropical regions of the world, but its normal status in whole grain is that of a secondary pest requiring prior infestation by an internal feeder or some form of mechanical damage (Gupta and Singh, 1996).

This beetle can be found all over the world mainly because of international trade of agricultural products (Oliveira *et al.*, 2006).

Although cosmopolitan, *T. castaneum* is particularly a pest of tropical, subtropical and warm areas where it thrives in both grains and mills (Mutambuki and Harberd, 2004).

The red flour beetle is of Indo-Australian origin (Smith and Whitman, 1992) and is found in temperate areas, but survive the winter in protected places, especially where there is central heat (Tripathi *et al.,* 2001). In the United States, it is found primarily in the southern states (Baldwin and Fasulo, 2007). The confused flour beetle, originally of African origin, has a different distribution in that it occurs worldwide in cooler climates and in the United States it is more abundant in the northern states (Smith and Whitman, 1992).

Description and life cycle of *Tribolium castaneum*: *T. castaneum* is small, reddish-brown beetle, about 3.5 mm long and it is similar in size and appearance as well as in life histories and habits with *T. confusum,* however, it can be distinguished from the later one with the aid of a hand lens (Ebeling, 2002). The red flour beetle is reddish-brown in color and its antennae end in a three-segmented club (Bousquet, 1990). Whereas the confused flour beetle is the same color but its antennae end is gradually club-like, the club consisting of four segments (Walter, 1990). Besides, *T. confusum* has the sides of the thorax almost straight, while those of *T. castaneum* are curved (Anonymous, 1986). Furthermore, *T. castaneum* species is distinct from other *Tribolium* spp. in having the ventral part of the eyes large, and relatively close together whereas *T. confusum* has smaller eyes set farther apart (Bousquet, 1990).

Although small beetles, the adults are long-lived and may live for more than three years (Walter, 1990). The female red flour beetle may copulate many times and they lay eggs in the commodity through out their adult lives, even though the number of egg laid depend upon temperature (Haines, 1991). Each flour beetle female deposits 400 to 500 clear-white, sticky eggs on or among food particles, in cracks, or through the meshes of sacks containing food, such as cereal products in her life time and she lays an average of 2.5 eggs each day (Howe, 1962), but she is long-lived, and may survive as long as 2 years (Baldwin and Fasulo, 2007). The tiny eggs hatch in 5 to 12 days into small, brownish-white larvae, which goes through 5 to 12 instars (Walter, 1990), then changed to pupa which lasts about 4.5 days (Haines, 1991) and reach maturity in as few as 20 days under optimum conditions (Mutambuki and Harberd, 2004), but may require up to 4 months (Walter, 1990).

The full-grown larvae are 4 to 5 mm long, slender, cylindrical, wiry in appearance, and white, tinged yellowish and can be distinguished from the larvae of other species that are somewhat similar in appearance by the prominent, 2-pointed termination of the last body segment. As the larvae mature, they come to the surface of the food medium to transform into naked white pupae (Baldwin and Fasulo, 2007). In heated storehouses and mills, there are 4 or 5 generations annually (Ebeling 2002). Good (1936) stated that the life cycle of *T. confusum* was 11 "somewhat longer" than that of *T. castaneum*, but that the optimum temperature appeared to be the same-30 °C (86 °F) for both species.

In infested flour, the larvae, pupae and adults of *T. castaneum* are visible due to their larger size but the eggs are difficult to distinguish from flour particles by naked eye. Flour particles may adhere to eggs making their identification difficult (Leelaja *et al*., 2007).

Habits of *Tribolium castaneum*: The adults are attracted to light, but will go towards cover when disturbed (Baldwin and Fasulo, 2007). The red flour beetles may be present in large numbers in infested grain, but are unable to attack sound or undamaged grain (Walter, 1990).

Typically, these beetles can be found not only inside infested grain products, but in cracks and crevices where grain may have spilled, are attracted to grain with high moisture content and can cause a grey tint to the grain they are infesting. Besides they give off a displeasing odor and their presence encourages mold growth in grain (Baldwin and Fasulo, 2007).

Cannibalism and predation play an important role in the nutrition of *T.castaneum* in which the eggs and pupae are often cannibalised by adults, the males showing a preference for pupae and females for eggs. Besides predation on other insects, e.g. the eggs of the Indian meal moth, *Plodia interpunctella*, provides a dietary supplement that increases the rate of development and reduces mortality (Mutambuki and Harberd, 2004).

T. castaneum is a facultative predator and scavenger. Both adults and larvae of *T. castaneum* are known to prey on immature stages of the rice moth, *Corcyra cephalonica*, a potential competitor within stored product environments. Adults and larvae are voracious predators of eggs and pupae, thus enhancing larval development or adult reproduction, thereby reducing competition for their progeny (Alabi *et al*. 2008).

3.4. Management methods of storage insect pests

Because food is susceptible to attack along the entire processing and marketing chain, pests must be controlled in diverse storage environments, including on-farm product storage, warehouses, food processing facilities, packinghouses, and retail outlets (Johnson, 2002). Overall, biotechnical, biological, cultural and chemical methods are crucial approaches for successful control of the most dominant stored product pests in general (Gwinner *et al*., 1990).

Cultural control: the use of various agricultural practices to make a habitat less suitable for reproduction and/or survival of pests is a long-established method of pest control, which aims, therefore, to reduce rather than eradicate pest populations and it is typically used in conjunction with other control methods. However, in some instances, cultural practices alone may effect almost complete control of a pest, as occurs with the tobacco hornworm (*Manduca sexta*) in North Carolina and the pink bollworm (*Pectinophora gossypiella*) on cotton in central Texas (Gillott, 2005).

The practices which have worked include ploughing, burning stubble, stubble retention, timing of planting, crop rotations, effect of fertilisers, use of susceptible trap crops to divert pests from the main crop, effects of shading, sanitation of fields and of equipment, and intercropping (http://www.natsoc org.au/htm/ papers/ rsmith. Pdf. browsed on04/04/2010). In cultural control, the methods used may directly affect a pest or stimulate an increase in density of a pest's natural enemies (Gillott, 2005).

Physical control: in physical control methods, the physical environment of the pest is modified in such a way that the insects no longer pose a threat to the agricultural crop, and this can be achieved by generating stress levels ranging from agitation to death or by using devices such as physical barriers that protect produce or plants from infestation. Many Physical control methods target an ensemble of physiological and behavioral processes, whereas chemical methods have well-defined and limited modes of action (Vincent *et al*., 2003)

The use of physical control measures include temperature, mechanical, moisture, relative humidity, structural (e.g. grain silos, packag-ing), irradiation, and sanitation, for example lower temperatures reduce the rate of development, feeding, reproduction, and survival (Herrman, 1998).

The use of heat and cold, irradiation microwaves and mechanical shock are promising alternatives in certain areas of species. Besides, inert dusts based on diatomaceous earths were proposed in the late 1930s and are now available for use in species (Scholler *et al.*, 1997). Inert dusts have been used traditionally as stored-grain protectants and a number of publications have reviewed their efficacy against stored-product insects (Collins, 2006).

Biological control: biological control is an often-underutilized component of integrated pest management of stored grain, and the use of natural enemies to control stored-grain insect pests may seem relatively new but, biological control was used as far back as 1911 to control Mediterranean flour moth (Flinn and Hagstrum, 2001).

In biological control, natural enemies (predators, parasitoids or pathogens) are used to keep pest populations at acceptable levels, usually in combination with other control methods. Predators, such as spiders, ladybirds, lacewings or predatory mites, usually feed on a range of different insects but parasitoids lay eggs on one host insect, and the larvae live and feed on the host, which dies (true parasites do not kill their hosts). Pathogens may be (bacteria, fungi, viruses, nematodes or protozoa (http://www.natsocorg.au/htm/papers/rsmith.Pdf browsed on 04/04/2010).

Detailed information on the biology, behaviour and life history of the pest and the natural enemy is vital for the successful use of entomophagous insects to control stored product insect pests. The species of natural enemies differ significantly in their biology and behaviour and therefore in their potential to reduce pests in each stored product environment (Scholler *et al.*, 1997).

Biological control (including natural control, augmentation, and classical control) offers several advantages over control by insecticides such as the control agent is ready-made (does not have to be developed or go through an extensive registration process), cheap to produce and apply, and persistent (exceptions to many microbial insecticides); it does not endanger humans or wildlife through pollution of the environment; and the method does not stimulate rapid genetic counterattack by pests (though examples of developing resistance to microbial insecticides are known). Its main disadvantages are its slowness of effect, the fact that the final (equilibrium) pest population density is normally higher than that achieved after insecticide application and from some biological control projects include (of both the original pest and non-pest species), enhancement of the target pest population as a result of secondary outbreaks, and change to pest status for the original control agent (Gillott, 2005).

Stored product insects can survive on small amounts of food that accumulate in inaccessible places, such as cracks and crevices, under perforated floors, and inside machinery, and may move from these refugia into packaged and bulk-stored products (Campbell *et al*., 2004). Biological control may be an effective strategy for stored-product pest management in these inaccessible locations, because some natural enemies can actively seek out pests in these hidden habitats or may be applied in a manner similar to chemical pesticides, however, most of the previous work on biological control of stored-product pests has focused on bulk-grain situations (Ramos-Rodryguez *et al*., 2006). For example, parasitic wasps (e.g. *Theocolax elegans* and *Anisopteromalus calandrae* have been shown to suppress pest populations effectively in bulk storage (Scholler and Flinn, 2000).

While biological control agents may occur naturally via stored products, the application of pesticides to control target pests can have a more deleterious effect on the parasitoid. Once the biological control agent is removed, pest resurgence can occur resulting in an even higher infestation level (Herrman, 1998).

Biological antagonists could be effective especially in the early stages of insect infestation in which natural enemies should fit into the total stored product pest management programme and not be seen as an endeavour separate from other stored product protection measures. Predators and parasitoids have the ability to actively detect and kill pest insects. Natural enemies are known for all major stored product pest insects (Scholler *et al*., 1997).

Host plant resistance: resistance of plant or plant materials to insects is defined as the relative amount of heritable qualities possessed by a plant or its materials (for example, its seeds) which influence the ultimate degree of damage done by the insects (mbata, 1997). for stored grains, resistance represents the ability of a certain crop variety to produce grains that maintain better quality than commonly cultivated varieties following long storage under similar insect populations (mbata, 1987).

Use of resistant varieties is the most cheap, effective and ecologically safe method of protecting grains against insect pests since there is no special technology which has to be adopted by the farmer (Helbig, 1997). In addition, pests that feed on these plants may be more susceptible to disease, adverse weather conditions, and insecticides, which can therefore be used in lesser amounts, however, disadvantages include the length of time required to develop a resistant variety, ordinarily 10–15 years with crop plants and even longer with trees (Gillott, 2005).

The expenses to the farmer are limited because he only has to buy the seed and health risks associated with insecticide application are avoided and it is therefore, evident that breeding for resistance to post–harvest pests is important for small and large–scale farmers alike (Ahmed and Yusuf, 2007).

In stored grains several factors lead to the production of resistance against infestation by storage insect pests. These include the tightness of the glumes in un milled rice (Haryadi and Fleurat–Lassard, 1991) which serve as physical barrier working against penetration by insects; well–fitting and tight–sheating leaves of the husks covering a maize cob (Kossou *et al*., 1993) may reduce infestation by *Sitophilus* spp. in the field and in store; hardness of seeds (Jansen, 1977) is thought to make insect penetration more difficult thus providing protection; seed size (Dharmasena and Subasinghe, 1986) has also been shown to influence infestation by insect pests as large grain legumes provide more surface area for oviposition and larval development than small–size grains; the texture and hairiness of cowpea seed; (Ofuya and Awelewa, 1993) may have negative influence on the oviposition of the cowpea weevil; the quantity and quality of nutritional constituents (Consoli and Amaral-Filho, 1995) have been described to have influence on the fecundity of the females, on the development period of the pre- imaginal instars and on the rate of adult emergence; the presence of compounds which inhibit oviposition and the development of insects on seeds (Desroches *et al*., 1995).

Chemical control: Chemical control traditionally has been the use of naturally occurring or synthetic chemicals to kill pests and it has been the major method of pest control for about 90 years but, has created three serious problems such as a great increase in the resistance of pests to the chemicals, the death of many beneficial insects as a result of the chemicals' non-specific activity and pollution of the environment (Gillott, 2005).

There are many different insecticides that kill insects, but only few of which can be used to control storage pest insects, because there are strict regulations on the use of pesticides on or near foodstuffs and hence, insecticides that need a long time to degrade and as such leave residues in the product are unsuitable for use on stored produce since residues of chemicals cause health problems when eaten by human beings or livestock (Groo, 2004).

Insect growth regulators have found use in specific situations where rapid knock down is not critical, and sex attractants and aggregation pheromones now play major roles in monitoring systems for estimating pest populations (Gillott, 2005).

Synthetic contact insecticides and fumigants are still the main component of IPM in stored product protection and efficacy and costs of control measures with these substances currently set the standard of efficiency. Effective application methods, dosage reductions and reduced pollution of the environment as well as recapture of insecticides and other modifications such as the combination of several lethal factors (e.g. phosphine and heat) are being developed to refine the use of chemicals in spp. (Scholler *et al.*, 1997).

Insect growth regulators (IGRs): IGRs are compounds that disrupt the normal development of insects by mimicking the action of insect hormones and/or by interfering with hormone regulated processes and they have been used in a variety of practical applications and are effective against a range of stored-product insects (Collins, 2006).

Insect growth regulators (IGRs) used in stored product systems in the United States and elsewhere include the insect juvenile hormone analogs methoprene, hydroprene, and pyriproxyfen and all these three compounds mimic the effects of sustained increased titer of insect juvenile hormone by disrupting normal development between larval instars and in metamorphosis from larvae to pupae and then from pupae to normal adults, however, these IGRs are not directly toxic to adults, although their potential effects on reproductive sterility have not been fully investigated, and they have another key attribute such as their low levels of toxicity to mammals and inherent high level of food safety (Phillips and Throne, 2010).

Besides, among the effects of these IGRs are interference with embryogenesis, followed by death, at IGR doses about 1/1000th the value of conventional ovicides; abnormal development of the integument in postembryonic stages, leading to inability to molt properly and impaired sensory function (hence inability to locate food, mates, oviposition sites, etc.); improper metamorphosis of internal organs or external genitalia, causing sterility and/or inability to mate; interference with diapause, so that an insect becomes seasonally maladjusted; and abnormal polymorphism in aphids (Staal, 1975). Because these effects by which they take some time to manifest themselves, IGRs are less valuable against rapidly growing larval pests, however, a number of commercial preparations are now available for insects that are long-lived pests and/or pests in the adult stage, for example, fenoxycarb (livestock flies), methoprene (fleas, mosquitoes, stored product pests), hydroprene (cockroaches), and kinoprene (homopteran pests of greenhouses and ornamentals) (Gillott, 2005).

Pheromones: Pheromones and other semiochemicals (behavioral chemicals) play important roles in the lives of stored-product insects and hold great potential as tools for pest management (Phillips, 1997).

Attractant pheromones, which are intraspecific chemical signals, and other attractant semiochemicals have been identified for over 40 species of stored-product insects over the past 40 years (Chambers, 1990).

Besides, pheromones, semiochemicals that are intraspecific signals, have been chemically identified from over 35 species of stored-product insect pests, all beetles and moths (Phillips, 1997).

Moreover, pheromones have been identified for all important stored product pests and can serve as a tool to detect infestation at an early stage, to determine the right time for control measures and to prove the quality of a control measure (Scholler *et al.*, 1997). And pheromone-baited traps are well-established monitoring devices (Levinson and Levinson, 1995).

As in other insects, pheromones of storage pests are volatile, low molecular weight organic compounds of various structures and are classified as either sex pheromones, which are produced by one sex (usually the female) and attract members of the opposite sex for mating, or as aggregation pheromones, which are produced by one sex (usually the male) and attract members of both sexes resulting in mating and aggregation at a food resource (Phillips, 1997). In fact it is believed that both sex and aggregation pheromones evolved in the context of mating behavior, and thus all sex-specific adult pheromones of this nature could be considered 'sex' pheromones (Raffa *et al*., 1993). Among storage insects, female-produced sex pheromones are utilized by all moths and by beetles in the families Anobiidae, Bruchidae, and Dermestidae and the adults of these insects with sex pheromones tend to be relatively short-lived (days to weeks) and feed very little (beetles) or not at all (moths) before they mate and die (Phillips, 1997). Storage insects with male-produced aggregation pheromones include beetles in the families Bostrichidae, Cucujidae, Curculionidae, and Tenebrionidae, and these insects feed substantially and are relatively long-lived as adults (weeks to months) (Burkholder and Ma, 1985).

Pheromones are commercially available for approximately 20 species of stored-product insects as slow-release formulations of lures to be used in monitoring traps and among those that can be purchased, the most commonly used pheromones are those for *P. interpunctella*, the cigarette beetle, *Lasioderma serricorne* (Coleoptera: Anobiidae), the red and confused flour beetles, *T. castaneum* and *T. confusum*, respectively and the warehouse beetle, *Trogoderma variabile* Ballion (Coleoptera: Dermestidae) (Phillips and Throne, 2010).

Botanicals: Plant parts and extracts have been, and still are, used in many parts of the world to kill or repel insects. Plants are known to produce a range of secondary metabolites which can possess multiple modes of action, including acute toxicity, repellency, antifeedant or antioviposition effects and inhibition of growth, development or reproduction (Coats *et al.*, 1991).

There is a plethora of studies on the use of plant extracts or whole plant materials for insect control, but few are used on a commercial scale (Rajandran and Sriranjini, 2008)

Farmers often use home grown or naturally occurring plant materials for insect control in developing countries, but problems with botanical insecticides are lack of consistency, safety concerns, and sometimes odor (Phillips and Throne, 2010).

Natural compounds from plant sources may have the advantage over conventional fumigants in terms of low mammalian toxicity (not true in all cases), rapid degradation and local availability (Rajandran and Sriranjini, 2008).

It is often falsely assumed that because a plant material is used as a food, flavoring or medicine that extracts from the material will be safe for human consumption (Phillips and Throne, 2010).

Various extracts from the neem tree, *Azadirachta indica*, collectively referred to as the Insecticide neem, are commercially available botanical insecticides, and local formulations have been widely used in some parts of the world for stored-product insect control (Koul *et al*, 1990*)*. However, commercial formulations show only moderate levels of efficacy (Kavallieratos *et al*., 2007). Crude pea flour, and the protein-rich fraction of field peas, *Pisum* spp., as well as that of other food legumes (e.g., species of *Pissum*, *Phaseolus*, and *Vignia*), are toxic and repellent to stored-product insects (Fields, 2006)

Integrated pest management: integrated pest management (IPM), is a pest population management system that utilizes all suitable techniques either to reduce pest populations or maintain them at levels below those causing economic injury, or to so manipulate the populations that they are prevented from causing such injury (Gillott, 2005). Or it is a systematic approach to managing pests that focuses on long-term prevention or suppression with minimal impact on human health, the environment, and non-target organisms and it incorporates all reasonable measures to prevent pest problems by properly identifying pests, monitoring population dynamics, and using cultural, physical, biological, or chemical pest population control methods to reduce pests to acceptable levels (http://www.louisvilleky.gov/LWC browsed on 03 /03/2010).

There are three phases in the development of an IPM strategy: problem definition, research, and implementation, of which the first is the most important, and to be most effective, IPM requires the input of as much information as possible, not only about the agro ecosystem, but also about the socioeconomic framework of the farming system in which the pest problem occurs. Thus, the collaboration of experts from a wide range of disciplines is necessary and if conducted properly, IPM leads to considerable financial saving and a great improvement in environmental quality (Gillott, 2005).

IPM has been shown experimentally to be more effective than classical methods (such as biological or chemical control only) (Pedigo and Higley, 1992). Economic injury levels and ETs (economic threshold levels) are important components of a cost effective integrated pest management programme and are useful for decision-making in the applications of pesticides (Van Lenteren and Woets, 1988). An ET is usually defined as the number of insect pests in the field when control actions must be taken to prevent the economic injury level from being reached and exceeded and for an IPM strategy, action must be taken once a critical density of pests is observed in the field so that the economic injury level is not exceeded. Therefore, understanding and appropriate use of economic decision levels in dealing with pests can increase profits and maintain environmental quality (Tang and Cheke, 2008).

Management options for *Tribolium castaneum*: *T. castaneum* is an important worldwide pest of stored products that is observed among several commodities and it may cause considerable economical losses if not adequately controlled because it has a very high rate of population increase (Khashaveh *et al.*, 2009).

The control of pests in stored products, principally cereal grains, by use of the chemicals, a common strategy for post harvest loss avoidance, leads to the apparition of many problems like the pollution of environment, toxicity to human being, emergence of resistant pests' strains and many other damages (Schumutterer, 1990). These synthetic pesticides are expensive for the users and may cause potential risk due to the lack of technical knowledge related to their safe use. Among these unexpected effects, the development of resistance by some pests occurred and the lethal effect on non-target species are possibilities and it is the case of *T. castaneum* (Coleoptera, Tenebrionidae) which is nowadays one of the most resistant insects to industrial pesticides (Kouninki *et al.*, 2007). For more than 40 years, *T. castaneum* has shown its ability to develop resistance to insecticides, thus permitting resistant strains to spread geographically (Assie, 2007).

Moreover, *T. castaneum* is a major pest of cereal flour depreciating the quantity and quality of the food. In grain storage, it appears after the implementation of major grain pest as *Sitophilus* species and any treatment to cure attacks of this pest potentially leads to direct poisoning of consumers because the flour or main components of animal food treated by chemicals pesticides are directly consumed or used for the formulation of provender (Kouninki *et al,* 2007). Chemical insecticides cannot be mixed with flour or provender because of their adverse effect on food quality **(**Schumutterer**,** 1990) and very little is reported on the use of chemical natural or synthetic to *T. castaneum* in flour or provender destined to the nourishment.

It becomes, therefore, useful to build up alternative methods of controlling pest by methods that are user-friendly as the use of agents with high efficacy on the pest and low persistence in the food, and there are needs to develop and popularise such control techniques that are clean and user-friendly i.e. natural products like essential oils (Kouninki *et al.*, 2007). In the early seventies, an alternative was the use of natural products as pesticides to control pests during storage; some of these natural products protect grain without any observed effects on their germination, their smell and their taste (Szafranski, 1991). Ethno botany has therefore, played a very important role in the protection of crops against pests in Africa and Asia **(**Hassanali *et al.*, 1990).

Although a large number of plant products in various forms have been screened against major pests of stored grain, thousands are still untouched. Plants, which have rich source of secondary metabolites, act as insecticides, ovicidal, ovipositional deterrents, feeding deterrents and growth retardants and most of the plant products are non-pollutant, less toxic and are easily biodegradable in nature (Pugazhvendan *et al.,* 2009). The application of botanical insecticides for the protection of cereals and pulses is currently one of the major foci of research in many developing countries (Ajayi, 2007).

Besides, combinations of physical and biological methods can be integrated to increase efficiency in the control of pests, and also to decrease the use of chemical products, the impact on beneficial species and costs **(**Lorini and Beckel, 2005). Integrated control depends on the understanding of the storing ecosystem, including pest population dynamics and precise methods for monitoring population levels of these pests (Arbogast *et al.*, 1998).

A stored product integrated pest management (IPM) program usually emphasizes the prevention of established pest populations through the use of quick, targeted responses, used to suppress pests when they do become established (Campbell *et al*., 2002).

Comprehensive IPM programs designed for commercial food processing facilities typically rely on an effective monitoring system to obtain reliable information about insect populations (Hagstrum and Flinn, 1996), often utilizing pheromone-baited traps for monitoring purposes (Campbell *et al*., 2002). Successful and comprehensive IPM programs designed for commercial food processing facilities also typically rely on controlled application of residual insecticides. Other recommended components include sanitation, such as cleaning the inside of mills and warehouses by eliminating food sources that can otherwise support infestations (Hedges and Lacey, 1996).

Flour beetles feed and survive on small amounts of grain and flour; hence, sanitation as a component of IPM plays a crucial role in controlling these pests by eliminating food resources necessary for larval growth and development (Mahroof *et al*., 2005).

An effective stored product IPM program emphasizes the prevention of pest populations from becoming established, and allows for a quick targeted response to suppress pests when they do become established (Faustini, 2006)

4. MATERIAL AND METHODS

4.1. Mass rearing of test insects

Adult *Tribolium castaneum* were obtained from Addis Ababa University insect science laboratory and reared on broken grains and flour of different cereal grains (maize, barely, wheat, and sorghum) at 27±2 ºC and 60-65% relative humidity following the method of Bekele Jembere *et al* (1995).

4.2. Grain collection and preparation

One and half k.g. of each grain were purchased from Merkato (Ehil-berenda) and ground in to different textures with grinding mill and to flour form by using an electric milling machine. Two different levels of percentages of broken or unbroken grains were produced by calculating the different percentages from 20 g of different grains, thus constituting 10 (mechanically damaged) and 50% broken (coarse), and whole flour were produced by using an electric milling machine as mentioned above. These10 and 50% broken, whole flour, and whole grain (control) were kept in an oven at 40 C for four hours to disinfest from internal infestation. Then 20 g of each of the four distinct textures (including the control) of the grains were put in 32 one liter capacity glass jars each and 7 pairs of 1-3days old adult *Tribolium castaneum* were introduced in each jar containing 20 g of each of the three distinct forms of the grains. The jars were then covered with nylon mesh and held in a place with rubber bands to allow ventilation and to prevent the escape of the experimental insects. Then the different textures of the grains in each of the 32 glass jars were kept under laboratory condition and female beetles were allowed to lay eggs for 20 days after which all dead or live insects were removed with sieve and counted. Thereafter, the treatments were left and checked daily until larva, pupa and adult emergence respectively. Larva, pupa and adult emergence in each treatment was taken and recorded for 12, 5 and 20 days in succession in each replicate or treatment texture from the start of larva, pupa and adult emergence, respectively. All adults that emerged were removed from each treatment at the time of final recording for a period of two generations. The experiment was set up in a completely randomized design in three replications in factorial arrangement.

4.3. Determination of parental and filial generations' adults' mortality and filial generations' larvae, pupae and adults emergence of *T. Castaneum*.

Data were collected on number of larvae, number of pupae and number of adults (number of dead and live parental adults after 20 days of oviposition and number of adult progenies) to determine Parental and filial generations' adults' mortality and filial generations' emergence of *T. Castaneum.*

The treatments were Grain status **(**whole grain mechanically damaged coarse and flour) and grain type such as cereals (maize, wheat, sorghum, barely) and pulses (field pea, haricot bean, faba bean, chick pea).

4.3. DATA ANALYSIS

Data entry and analysis were done using Microsoft Excel, SAS and MSTAT soft wares. Data were transformed using log transformation and again back transformed in to the original data for presentation. To observe the effect of treatment on parental adults' mortality, adults' progenies mortality and larvae, pupae and adults progenies development in the above experiment, appropriate statistical method, two way ANOVA was used and significant differences between the means was separated using Tukey's honestly significant difference (HSD) test.

5. RESULTS

5.1. The effect of different types of grains in different textures on the mortality of parental *Tribolium castaneum* adults

Results on the mortality of *T. castaneum* parental adults starting from introduction of the parental adults in to four distinct textures (whole grain, mechanically damaged, cores and flour textures) of eight types of grains (maize, barely, wheat, sorghum, chick pea, faba bean, field pea and haricot bean) up to 20 days of ovipsition are shown in Table 1.

The mean mortality of parental adult flour beetles was significantly ($P < 0.05$) lower in maize, barely, wheat and sorghum on mechanically damaged, cores and flour textures than in the rest of the hosts (chick pea, faba bean, field pea and haricot bean) of similar textures.

Besides in barely, wheat, faba bean, field pea and haricot bean whole grain, almost all the parental adults were died and there was no significant difference ($P > 0.05$) between the cumulative mean mortality of each type of the whole grains.

Further more, no parental adults died on barley flour texture, but all parental adults were died on field pea and haricot bean mechanically damaged textures (Table 1)

Table 1. Mean number (Mean± SE) mortality of introduced *T. castaneum* adults

Hosts	Whole grains(control)	Mechanically damaged grains (50%)	Coarse (50%)	Flour
Maize	13.99±0.00Aa	0.99±0.59Bd	0.82±0.45Bd	0.58±0.29Bd
Barely	13.79±0.00Aa	1.00±0.60Bd	0.59±0.29Bd	0.00±0.00Bd
Wheat	13.66±0.02Aa	2.45±0.76Bc	0.58±0.76Cd	0.44±0.54Cd
Sorghum	13.29±0.04Aa	2.63±0.44Bc	2.28±0.66Bc	2.08±0.00Bc
Chick pea	11.58±0.08Aa	7.31±0.34ABb	5.80±0.20ABb	4.13±0.44Bb
Faba bean	13.99±0.00Aa	12.96±0.04ABa	11.58±0.07ABa	13.29±0.05 Aa
Field pea	14.00±0.00Aa	13.99±0.00Aa	13.29±0.05 Aa	12.64±0.24ABa
Haricot bean	14.00±0.00Aa	14.00±0.00Aa	12.90±0.08ABa	11.30±0.03ABa

Means followed by the same letters with in row (upper case letters) and with in columns (lower case letters) are not significantly different, P> 0.05%, Tukey's studentized range test (HSD).

5.2. The effect of different types of grains in different textures on the mortality of 1st and2nd generation *Tribolium Castaneum* adults.

Results on the mortality of *T. castaneum* 1st and 2nd generation adults from the start of adult emergence in four distinct textures (whole grain, mechanically damaged, cores and flour textures) of eight types of grains (maize, barely, wheat, sorghum, chick pea, faba bean, field pea and haricot bean) up to 20 days period are shown in Tables 2 and 3.

The mean mortality (tables 2 and 3) of flour beetles was significantly ($P< 0.05$) lower in chick pea, faba bean, field pea and haricot bean mechanically damaged, cores and flour textures than in the rest of the hosts (maize, barely, wheat, sorghum) of similar textures in both the 1st and 2nd generations.

Besides in maize, barely, wheat, sorghum (cereals) whole grains and chick pea, faba bean, field pea and haricot bean (pulses) mechanically damaged, cores and flour textures almost all of the adults were died (Tables 2 and 3) both the in first and second generations. And there was no significant difference ($P> 0.05$) between the cumulative mean mortality of each type of the whole grains and pulses both in the 1st and 2nd generations.

Further more, tables 2 and 3, also indicated that more *T. castaneum* were died during the second generation than in the first generation in almost all hosts (grains)

Table 2. Mean (Mean± SE) mortality of first generation adult progeny of *T. castaneum*

Hosts	Whole grains(control)	Mechanically damaged grains (50%)	Coarse (50%)	Flour
Maize	0.00±0.00Ba	2.63±0.10Aa	1.63±0.16Aa	1.29±0.15Aa
Barely	0.00±0.00Ba	2.24±0.10Aa	1.29±0.16Aa	0.00±0.00Bb
Wheat	0.00±0.00Ba	2.98±0.00Aa	2.30±0.10Aa	0.82±0.45Ba
Sorghum	0.00±0.00Ba	3.64±0.06Aa	2.31±0.1ABa	1.88±0.25 ABa
Chick pea	0.00±0.00Aa	0.00±0.00Ab	0.00±0.00Ab	0.00±0.00Ab
Faba bean	0.00±0.00Aa	0.00±0.00Ab	0.00±0.00Ab	0.00±0.00Ab
Field pea	0.00±0.00Aa	0.00±0.00Ab	0.00±0.00Ab	0.00±0.00 Ab
Haricot bean	0.00±0.00Aa	0.00±0.00Ab	0.00±0.00Ab	0.00±0.00Ab

Means followed by the same letters with in row (upper case letters) and with in columns (lower case letters) are not significantly different, P> 0.05, Tukey's studentized range test (HSD).

Table 3. Mean (Mean± SE) mortality of second generation adult progeny of *T. castaneum*

Hosts	Whole grains(control)	Mechanically damaged grains (10%)	Cores (50%)	Flour
Maize	0.00±0.00Ca	13.05±0.05Aa	10.77±0.049Bb	9.66±0.06Ba
Barely	0.00±0.00Ca	10.49±0.03Ab	8.56±0.04Bc	7.94±0.07Bb
Wheat	0.00±0.00Ca	13.05±0.05Aa	11.34±0.08ABa	9.67±0.06Ba
Sorghum	0.00±0.00Ca	14.86±0.04Aa	12.26±0.11ABa	10.30±0.03Ba
Chick pea	0.00±0.00Aa	0.00±0.00Ac	0.00±0.00Ad	0.00±0.00Ac
Faba bean	0.00±0.00Aa	0.00±0.00Ac	0.00±0.00Ad	0.00±0.00Ac
Field pea	0.00±0.00Aa	0.00±0.00Ac	0.00±0.00Ad	0.00±0.00Ac
Haricot bean	0.00±0.00Aa	0.00±0.00Ac	0.00±0.00Ad	0.00±0.00Ac

Means followed by the same letters with in row (upper case letters) and with in columns (lower case letters) are not significantly different, P> 0.05, Tukey's studentized range test (HSD).

5.3. The effect of different types of grains in different textures on the development of first and second generation (F_1 and F_2) of *T. Castaneum* larvae.

Results on F_1 and F_2 larvae progenies development of *T. Castaneum* due to the different types of grain in different textures are presented in tables 4 and 5.

The mean numbers of $F_1$and F_2 *Tribolium castaneum* larvae progenies produced in flour, cores, and mechanically damaged textures of barley, maize, wheat and sorghum respectively (i.e. cereals) were significantly ($P< 0.05$) high as compared to in similar textures of the rest of the hosts (i.e. pulses) both in the first and second generations. These mean numbers of $F_1$and F_2 *Tribolium castaneum* larvae progenies produced in the above mentioned textures of cereals were also significantly ($P< 0.05$) higher as compared to the control (whole grains) in both the first and second generations (Tables 4 and 5).

Besides, among different types of grains in different textures, significantly ($P< 0.05$) higher $F_1$and F_2 *Tribolium castaneum* larvae progenies were produced in cereals flour and coarse textures respectively, (the highest being in barely flour texture and in barely and maize coarse textures, respectively) as compared to mechanically damaged texture of all the grains in both the 1^{st} and 2^{nd} generations, except for sorghum coarse and mechanically damaged textures in which the progenies were equal in1^{st}generation. However, as mentioned above, the mean number of $F_1$and F_2 *Tribolium castaneum* larvae progenies produced in mechanically damaged textures of cereal grains were significantly ($P< 0.05$) higher as compared to the control (whole grains) in both the 1^{st} and 2^{nd} generations (Tables 4 and 5).

Generally, from the data obtained on the effect of eight different type of grains in four different forms on the development of mean number of first and second generations (F_1 and F_2) of *T. Castaneum* larvae progenies (Tables 4 and 5), the table showed that significantly ($P< 0.05$) more number of *T. castaneum* larvae was recorded in flour, cores and mechanically damaged textures respectively than in unbroken form (control) of cereal grains (maize, barely, wheat and sorghum) both in the 1^{st} and 2^{nd} generations. The table also showed that more *T. castaneum* larvae were emerged during the first generation than in the second generation period of emergence in all hosts (grains). (N.B. The mean numbers of larva progenies of 2nd generation shown in the table were resulted from the whole F_1 progenies. When these mean numbers of larvae progenies were computed for 14 parental adults (14 F_1adults), so that they could compared with F_1 generation that were produced by 14 parental adults by which the experiment was started, they were small (compared to the mean numbers of F_1 generation)). Besides significantly less ($P< 0.05$) mean numbers of larvae were emerged in whole unbroken texture of all grains in the 1st generation and both in unbroken texture and in all the rest textures of pulses in 2nd generation when compared with the numbers that developed in broken (damaged) texture of all grains in the first generation and in broken textures of all cereal grains in the 2nd generations.

Table 4. The effect of different types of grains in different textures on the emergence of first generation (F1) of *T. castaneum* larvae(Mean± SE).

Hosts	Whole grains(control)	Mechanically damaged grains (10%)	Coarse (50%)	Flour
Maize	0.58±0.55Da	27.84±0.03Cb	46.86±0.03Ba	104.1±0.01Ab
Barely	0.00±0.0 0Da	37.91±0.01Ba	47.28±0.15Ba	116.5±0.01Aa
Wheat	0.00±0.00Ca	23.56±0.05Bb	27.89±0.06Bb	101.36±0.05Ab
Sorghum	0.00±0.00Da	13.82±0.074Cc	23.56±0.17Bb	92.98±0. 17Ac
Chick pea	0.00±0.00 Ba	2.01±0.00Bd	3.15±0.49Bc	6.41±0.04Ad
Faba bean	0.00±0.00 Aa	0.00±0.00Ad	1.24±0.55Ac	1.31±0.16Ae
Field pea	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ac	2.16±1.35Ae
Haricot bean	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ac	0.55±0.29Ae

Means followed by the different letters with in row (upper case letters) and with in columns (lower case letters) are significantly different, P< 0.05, Tukey's studentized range test (HSD).

Table 5. The effect of different types of grains in different textures on the emergence of second generation (F2) of *T. castaneum* larvae(Mean± SE).

Hosts	Whole grains (control)	Mechanically damaged grains (10%)	Cores (50%)	Flour
Maize	0.00±0.00Da	37.02±0.01Cb	101.33±0.01Bb	280.83±0.00Ab
Barely	0.00±0.00Da	60.68±.03Ca	111.98±.01Ba	337.84±.00Aa
Wheat	0.00±0.00Da	15.23±0.04Cc	36.16±0.02Bc	125.77±0.01Ac
Sorghum	0.00±0.00Da	32.89±0.02Cb	41.98±0.04Bc	111.98±0.01Ad
Chick pea	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ae
Faba bean	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ae
Field pea	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ae
Haricot bean	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ae

Means followed by the different letters with in row (upper case letters) and with in columns (lower case letters) are significantly different, P< 0.05, Tukey's studentized range test (HSD).

5.4. The effect of different types of grains in different textures on the emergence of first and second generation (F1 and F2) of *T. castaneum* pupae.

Results on F_1 and F_2 pupae progenies development of *T. Castaneum* due to the different types of grain in different textures are presented in tables 6 and 7.

In the same manner with larvae progenies mentioned above, the mean numbers of $F_1$and F_2 *T. castaneum* pupae progenies produced in flour, cores and mechanically damaged textures of barley, maize, wheat and sorghum respectively (i.e. cereals) were significantly (P< 0.05) high as compared to in the same textures of the rest of the hosts (i.e. pulses) both in first and second generations. These mean numbers of $F_1$and F_2 *T. castaneum* pupae progenies produced in the above mentioned textures of cereals were also significantly (P< 0.05) higher as compared to the control (whole grain) in both the first and the second generations (Tables 6 and7).

Besides, in the similar manner with larvae progenies mentioned above, among different types of grains in different textures, significantly (P< 0.05) higher $F_1$and F_2 *T. castaneum* pupae progenies were produced in cereals flour and coarse textures respectively, (the highest being in barely flour textures and in barely and maize coarse textures, respectively) as compared to mechanically damaged texture of all the grains in both the 1^{st} and 2^{nd} generations, except for sorghum coarse and mechanically damaged textures in which the progenies were equal in1^{st}generations. However, the mean number of $F_1$and F_2 *T. castaneum* pupae progenies produced in mechanically damaged textures of cereal grains were significantly (P< 0.05) higher as compared to the control, as mentioned above (Tables 6 and7).

Generally, in the same way with larvae progenies mentioned above, from the data obtained on the effect of different type of grains in three different textures on the development of mean of first and second generations (F_1 and F_2) of *T. Castaneum* pupae progenies (Tables 6 and7), the table showed that significantly (P< 0.05) more number of *T. castaneum* pupae was recorded in flour, cores and mechanically damaged textures of the cereal grains respectively than in unbroken texture (control) of cereal grains (maize, barely, wheat and sorghum) both in the 1^{st} and 2^{nd} generations. The table also showed that more *T. castaneum* pupae were emerged during the first generation than in the second generation period of emergence in all hosts (grains). (N.B. The mean numbers of pupae progenies of 2nd generation shown in the table were resulted from the whole F_1 progenies. When these mean numbers of pupae progenies were computed for 14 parental adults (14 F_1adults), so that they could compared with F_1 generation that were produced by 14 parental adults by which the experiment was started, they were small (compared to the mean numbers of F_1 generation)). Besides significantly less ($P< 0.05$) mean numbers of pupae were emerged in whole unbroken texture of all grains in the 1st generation and both in whole unbroken texture and in all the rest textures of pulses in the 2nd generation when compared with the numbers that developed in broken (damaged) texture of all grains in the first generation and in broken textures of all cereal grains in the 2nd generation.

Table 6. The effect of different types of grains in different textures on the emergence of first generation (F_1) of *T. castaneum* pupae(Mean± SE).

Hosts	Whole grains(control)	Mechanically damaged grains (10%)	Coarse (50%)	Flour
Maize	0.44±0.29Da	25.30±0.05Cb	44.71±0.05Ba	99.00±0.00Ab
Barely	0.00±0.00Da	34.49±0.03Ca	42.66±0.02Ba	114.61±0.01Aa
Wheat	0.00±0.00Da	13.17±0.09Cc	26.57±0.05Bb	99.02±0.02Ab
Sorghum	0.00±0.00Da	20.40±0.03Cb	44.44±0.14Ba	90.83±004Ac
Chick pea	0.00±0.00Ba	1.66±0.16Bd	2.54±0.37FBd	5.72±0.05Ad
Faba bean	0.00±0.00Aa	0.00±0.00Ad	0.63±0.29GAd	0.92±0.45 Ae
Field pea	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	2.04±1.18Ae
Haricot bean	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ae

Means followed by the different letters with in row (upper case letters) and with in columns (lower case letters) are significantly different, P< 0.05, Tukey's studentized range test (HSD).

Table 7. The effect of different types of grains in different textures on the emergence of second generation (F_2) of *T. castaneum* pupae(Mean± SE).

Hosts	Whole grains(control)	Mechanically damaged grains (10%)	Cores (50%)	Flour
Maize	0.00±0.00Da	33.67±0.01Cb	92.33±0.01Bb	268.16±0.01Ab
Barely	0.00±0.00Da	60.68±0.03Ca	103.73±0.02Ba	337.84±0.00Aa
Wheat	0.00±0.00Da	14.04±0.04Cd	31.37±0.02Bc	113.83±0.01Ac
Sorghum	0.00±0.00Ca	30.41±0.03Bc	36.17±0.04Bc	108.65±0.01Ac
Chick pea	0.00±0.00Aa	0.00±0.00Ae	0.00±0.00Ad	0.00±0.00Ad
Faba bean	0.00±0.00Aa	0.00±0.00Ae	0.00±0.00Ad	0.00±0.00Ad
Field pea	0.00±0.00Aa	0.00±0.00Ae	0.00±0.00Ad	0.00±0.00Ad
Haricotbean	0.00±0.00Aa	0.00±0.00Ae	0.00±0.00Ad	0.00±0.00Ad

Means followed by the different letters with in row (upper case letters) and with in columns (lower case letters) are significantly different, P< 0.05, Tukey's studentized range test (HSD)

5.4. The effect of different types of grains in different textures on the development of mean first and second generation (F_1 and F_2) of *T. Castaneum* adults.

Results on F_1 and F_2 adults progenies development of *T. Castaneum* due to the different types of grain in different textures are presented in tables 8 and 9.

In the similar manner with larvae and pupae progenies mentioned above, the mean numbers of $F_1$and F_2 *T. castaneum* adults progenies produced in mechanically damaged, cores and flour textures of barley, maize, wheat and sorghum respectively (i.e. cereals) were significantly ($P< 0.05$) high as compared to textures of the rest of the hosts (i.e. pulses) both in the first and second generations. These mean numbers of $F_1$and F_2 *T. castaneum* adults progenies produced in the above mentioned textures of cereals were also significantly ($P< 0.05$) higher as compared to the control (whole grain) in both the first and second generations (Tables 8 and 9).

Besides, in the same way with larvae and pupae progenies mentioned above, among different textures different types of grains in different textures, significantly ($P< 0.05$) higher $F_1$and F_2 *T. castaneum* adults progenies were produced in cereals flour and coarse textures respectively, (the highest being in barely flour form and in barely and maize coarse forms respectively) as compared to mechanically damaged texture of all the grains in both the 1st and 2nd generations, except for sorghum coarse and mechanically damaged textures in which the progenies were equal in the 1st generation. However, the mean number of $F_1$and F_2 *T. castaneum* larvae progenies produced in mechanically damaged textures of cereal grains were significantly ($P< 0.05$) higher as compared to the control as mentioned above (Tables 8 and 9).

Generally, in the same manner with larvae and pupae progenies mentioned above, from the data obtained on the effect of different type of grains in three different textures on the development of mean of fist and second generations (F_1 and F_2) of *T. Castaneum* adults progenies (tables 8 and 9), the table showed that significantly ($P< 0.05$) more number of *T. castaneum* adults were recorded in flour, cores and mechanically damaged textures of the cereal grains respectively than in unbroken texture (control) of cereal grains (maize, barely, wheat and sorghum) both in the 1st and 2nd generations. The table also showed that more *T. castaneum* adults were emerged during the first generation than in the second generation period of emergence in all hosts (grains) (N.B. The mean numbers of pupae progenies of 2nd generation shown in the table were resulted from the whole F1 progenies. When these mean numbers of pupae progenies were computed for 14 parental adults (14 F_1adults), so that they could compared with F_1 generation that were produced by 14 parental adults by which the experiment was started, they were small (compared to the mean numbers of F_1 generation)). Besides significantly less ($P< 0.05$) mean numbers of adults were emerged in whole unbroken texture of all grains in the 1st generation and both in whole unbroken texture and in all the rest textures of pulses in the 2nd generation when compared with the numbers that developed in broken (damaged) texture of all grains in the first generation and in broken textures of all cereal grains in the 2nd generation.

Table 8. The effect of different types of grains in different textures on the development of mean number of fist generation (F_1) of *T. Castaneum* adults(Mean± SE).

Hosts	Whole grains (control)	Mechanically damaged grains (10%)	Coarse (50%)	Flour
Maize	0.26±0.29Da	20.88±0.08Cb	40.69±0.04Ba	98.3±0.01A a
Barely	0.00±0.00Da	31.45±0.03Ca	41.67±0.03Ba	100.57±0.02Aa
Wheat	0.00±0.00Da	11.63±0.08Cc	24.75±0.06Ba	96.73±0.01Aa
Sorghum	0.00±0.00Ca	17.63±0.06Bb	17.98±0.18Ba	88.75±0.01Ab
Chick pea	0.00±0.00Ba	0.63±0.29Bd	1.94±0.25Bc	4.38±0.07Ac
Faba bean	0.00±0.00Aa	0.00±.00Ad	0.29±0.29Ac	0.29±0.29Ad
Field pea	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ac	1.18±1.18Ad
Haricot bean	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ac	0.00±0.00Ad

Means followed by the different letters with in row (upper case letters) and with in columns (lower case letters) are significantly different, P< 0.05, Tukey's studentized range test (HSD).

Table 9. The effect of different types of grains in different textures on the development of mean number of second generation (F_2) of *T. Castaneum* adults(Mean±SE)

Hosts	Whole grains (control)	Mechanically damaged grains (10%)	Cores (50%)	Flour
Maize	0.00±0.00Da	29.90±0.00Cb	84.71±0.02Bb	262.03±0.01Ab
Barely	0.00±0.00Da	58.34±0.02Ca	99.00±0.00Ba	301.00±.00Aa
Wheat	0.00±0.00Da	11.67±0.12Cc	29.21±0.02Bc	108.65±0.01Ac
Sorghum	0.00±0.00Da	25.94±0.0CFb	32.89±0.01Bc	103.72±0.01Ac
Chick pea	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ad
Faba bean	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ad
Field pea	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ad
Haricot bean	0.00±0.00Aa	0.00±0.00Ad	0.00±0.00Ad	0.00±0.00Ad

Means followed by the different letters with in row (upper case letters) and with in columns (lower case letters) are significantly different, P< 0.05, Tukey's studentized range test (HSD).

6. DISCUSSIONS

Results of the present laboratory study indicated that the development of *T. castaneunm* larvae, pupae and adults progenies were significantly ($P < 0.05$) higher in damaged textures of the cereals, but significantly ($P < 0.05$) lower in both damaged and undamaged textures of the pulses and in undamaged texture (whole grain or control) of cereals.

The death of all the parental adults confined on whole grains of maize, barely, wheat, sorghum, chick pea, faba bean, field pea and haricot bean was probably due to the hardness of these cultivars, making it difficult for the insects to feed on them. This finding is in line with Li and Arbogast (1991) who reported that seed hardness causes resistance of cereal grains to infestation by *T. castaneum*.

Both the lowest death and lowest survival of flour beetles in pulses (chick pea, faba bean, field pea and haricot bean) damaged textures and flours were probably due to the in appropriateness of this hosts to *T. casaneum* which result in more pre adult stage mortality and eggs in viability. Similarly Farrell *et al*., (2002), showed that *T. castaneum* feed on a range of commodity especially cereals, but also ground nuts, spices, coffee, cocoa, dried fruit and occasionally pulses.

The death (non survival) of almost all flour beetles in whole grain of all hosts (grains) was probably due to the hardness of these grains which resulted in more parental adults' mortality, eggs in viability or in more pre adult mortality. This is also in line with Li and Arbogast (1991).

The results in tables 4 and 5, 6 and 7, and 8 and 9 showed that both grain type (maize, barely, wheat, sorghum, chick pea, faba bean and field pea) and grains breakage in to mechanically damaged, coarse and flour textures have significant effect on the development of *T. castaneum* larvae, pupae and adults progenies. Similarly Appert (1987) reported that cereal cultivars differ in susceptibility to *T. castaneum* and traditional threshing can result in grain breakage which leads to infestation. And it was also reported that the method of milling can influence the vulnerability of cereals to *T. castaneum* (Lale *et al.*, 2000). Besides, Tanzubil (1991) also indicated that the traditional method of threshing millet heads before storage encourages and aggravates the development of *T. castaneum*. Moreover, it was also reported that the rust-red flour beetle, *T. castaneum,* is a major secondary pest of cereal grains and their products in storage (Haines, 1991).

According to the results of the current laboratory study from damaged textures of all the grains, flours and coarse textures respectively, were the most appropriate textures in almost all types of the cereal hosts for the development of *T. castaneum* larvae, pupae and adults progenies as compared to mechanically damaged texture. And even the mechanically damaged texture was the appropriate texture in almost all types of cereal hosts for the development of *T. castaneum* larvae, pupae and adults progenies as compared to the whole grain (the control). Similarly, Campbell and Runnion (2003) had reiterated (restated) the fact that *T. castaneum* is a polyphagous and cosmopolitan pest that feeds and thrives on broken grains of mostly flour meals. It was also indicated that both adults and larvae of *T. castaneum* feed on grain dust and broken grains, but not the undamaged whole grains and spends its entire life cycle outside grain kernels (Karunakaran et al. 2004). Earlier reports by Li and Arbogast (1991) also showed that *T. castaneum* exhibited high affinity for maize flour than cracked maize or undamaged maize. Damaged grains have been reported to release some volatile compounds and these facilitate the attraction of secondary pests by broken grains (Campbell and Runnion, 2003; Lale and Yusuf, 2001). In addition, in another reports, Gueye and Delobel (1999), had shown that food products prepared from flour derived from pearl millet were infested more than whole millet kernels by four secondary pests comprising *T. castaneum, T. confusum, Corcyra cephalonica* and *Ephestia cautella*.

However, among different type of the hosts in different textures the resultstables 4 and 5, 6 and 7, and 8 and 9 showed that except the flour texture of the chick pea in the first generation larvae, pupae and adults progenies, all forms (whole grain, mechanically damaged, coarse and flour textures) of all the pulses such as faba bean, field pea, haricot bean and the whole grain, the mechanically damaged, and the coarse textures of chick pea were not appropriate host types and host textures for the development of *T. castaneum* larvae, pupae and adults progenies both in 1st and 2nd generations. This is also in line with Farrell *et al*., (2002).

On the other hand, Mason (2003) reported that *T. castaneum* infest a wide range of commodities and products including legume seeds, barley, biscuits, breakfast cereals, cacao, corn, cornmeal, cottonseed, dried fruits, drugs, flour, milk chocolate, millet, oats, powdered milk, rice, rye, spices, sunflower seeds, wheat & wheat bran, herbarium and museum collections.

Results of the current laboratory study have also shown that except un damaged textures of maize undamaged/ unbroken grains were relatively resistant to the development of *T. castaneum* larvae, pupae and adults progenies, in comparison with broken grains or flour in all hosts in both1st and 2nd generations. In related studies, Lale and Yusuf (2001) and Ajayi (2007) reported that whole grains were significantly more resistant to infestation by *T. castaneum* than broken grains or whole flour derived from all the millet cultivars screened. Besides, the intact testa of grains has been reported to serve as mechanical barriers against infestation of whole grains by *T. castaneum* (Lale and Abdulrahman, 1999).

Results in tables 4-9 showed the inability of population to increase with increase in generation period from first to second. This inability of the pest to have a population surge (to increase strongly and suddenly) as the generation period increased was probably due to the type of diet used as substrate. Different workers reported that the quality of diet presented to *T. castaneum* plays a major role in their development and population abundance (Trematerra *et al*., 1999; Trematerra *et al*., 2000; Gueye and Delobel, 1999). Besides, it was also noted that nutritional quality of the flour medium is of the utmost importance to *Tribolium* spp. population dynamics, such that any slight change to the immediate environment can cause a significant decrease in the oviposition rate (Fedina and Lewis, 2007). The presence of the possibility of cannibalism and predation by both the adults and larvae of *T. castaneum* due to the volume of substrate presented to the test insect was also reported (Gupta and Singh, 1996). However, the aspects of quality of diet, cannibalism and predation were not investigated in this study. Moreover, it was also reported that as the population density increases, the shared flour medium that *Tribolium* spp. occupy begins to lose its nutritional quality, often accumulating waste products and other ethyl- and methyl benzoquinones, produced by adults and released as defensive compounds (Sokoloff, 1974). This density dependence has also been shown to cause extended larval developmental times (Kotaki and fujii, 1995), increased pre adult mortality due to cannibalism by the active adult and larvae stages on the inactive egg and pupae stages (Alabi *et al*., 2008), and further induced dispersal (Ziegler, 1977).

7. CONCLUSION AND RECOMMENDATION

7.1. CONCLUSION

- From the current laboratory study the following conclusion can be done:

- Cereals in general, barely in particular in damaged and flour forms are the most preferred hosts of *Tribolium Castaneum*.

- Except the chick pea flour only in the first generation, all tested pulses in all textures are not hosts to *Tribolium castaneum*

- For most of the hosts i.e. the grains (for almost all), the whole grains are more resistant to *T. castaneum* than broken grains or flour.

7. 2. RECOMMENDATIONS

- The present laboratory study was on the effect of different local hosts in different forms to some biological parameter of *Tribolium castaneum*. Nevertheless, further investigation of the effect of these different hosts in different forms for development of *Tribolium castaneum* larvae, pupae and adult progenies in real storage conditions need to be done.

- As *Tribolium castaneum* only attack damaged grains, care should be taken while harvesting trashing and transporting grains.

- Efforts to control *Tribolium castaneum*, should focus on cereals.

- Detailed studies to determine the effect of quality of diet, cannibalism and predation on the development of larvae, pupae and adult progenies are some points should be done.

- Farmers living in developing countries particularly in tropics and sub tropics, including Ethiopia are recommended to store sound (undamaged) grains so that it helps them to reduce the attack of their grains by the most economically important storage pest, *Triblium castanem.*

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DECLARATION

I hereby declare that this thesis work is entirely my own work and it has never been submitted as an exercise for a degree of any other university and that all sources of materials used for it have been duly acknowledged.

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This thesis has been submitted for examination with my approval as a university advisor.

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Approved by the Board of Examiners:

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Chairman Signature

9. APPENDICES

Annex 1. Summary table of analysis of variance (ANOVA) for mortality of mean number of parental adults of Tribolium castaneum in different textures of different grains (hosts).

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	9.17	7	1.31	42.63	<.0001
GF	4.82	3	1.61	52.31	<.0001
GT*GF	3.27	21	0.156	5.07	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 2. Summary table of analysis of variance (ANOVA) for mortality of mean number of 1st generation adults of *Tribolium castaneum* in different textures of different grains (hosts).

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	3.0471	7	0.443	95.16	<.0001
GF	1.1233	3	0.374	81.86	<.0001
GT*GF	1.199	21	0.057	12.48	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 3. Summary table of analysis of variance (ANOVA) for mortality of mean number of 2nd generation adults of *Tribolium castaneum* in different textures of different grains (hosts).

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	15.63	7	2.234	3319.93	<.0001
GF	5.24	3	1.748	2597.35	<.0001
GT*GF	5.26	21	0.251	372.84	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 4: Summary table of analysis of variance (ANOVA) for mean number of 1st generation *Tribolium castaneum* larvae progenies that developed in different forms of different grains (hosts).

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	28.63	7	4.09	253.89	<.0001
GF	18.16	3	6.05	375.76	<.0001
GT*GF	10.05	21	0.47	29.71	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 5: Summary table of analysis of variance (ANOVA) for mean number of 1st generation *Tribolium castaneum* larvae progenies that developed in different textures of different grains (hosts).

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	29.20	7	4.17	331.26	<.0001
GF	16.75	3	5.58	443.36	<.0001
GT*GF	10.29	21	0.48	38.92	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 6: Summary table of analysis of variance (ANOVA) for mean number of 1st generation *Tribolium castaneum* adults' progenies that developed in different forms of different grains (hosts)

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	29.42	7	4.20	359.41	<.0001
GF	15.45	3	5.15	440.38	<.0001
GT*GF	11	21	0.52	44.83	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 7: Summary table of analysis of variance (ANOVA) for mean number of 2nd generation *Tribolium castaneum* larvae progenies that developed in different textures of different grains (hosts).

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	48.21	7	6.89	91829.50	<.0001
GF	17.59	3	5.86	78194.70	<.0001
GT*GF	1852	21	0.88	11756.70	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 8: Summary table of analysis of variance (ANOVA) for mean number of 2nd generation *Tribolium castaneum* pupae progenies that developed in different textures of different grains (hosts)

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	46.26	7	6.61	82394.60	<.0001
GF	16.98	3	5.66	70570.80	<.0001
GT*GF	17.96	21	0.86	10667.10	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Annex 9: Summary table of analysis of variance (ANOVA) for mean number of 2nd generation *Tribolium castaneum* adults' progenies that developed in different textures of different grains (hosts)

Source of error	Sum of Squares	df	Mean Square	F	pr>F
GT	44.73	7	6.40	22064.00	<.0001
GF	16.63	3	5.54	19145.20	<.0001
GT*GS	17.67	21	0.84	2906.48	<.0001

Both of the treatments and their interaction are significant at $p<0.05$

Plate1. Partial view of grains kept in an oven

plate2. Partial view of mass rearing setup

plate3. Introduction of test insects

Plate 4. (a and b). Partial view of insect rearing setup where the jars were placed on the ladder in Insectary of Addis Ababa University


Plate 5. Adults that were sieved from of maize flour

Plate6. Adults counted from barely flour after they were sieved