INSECT DAMAGE

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization
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INSECT DAMAGE: Damage on Post-harvest

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1. Introduction

Insects are the most diverse species of animals living on earth. Apart from the open ocean, insects can be found in all habitats; swamps, jungles, deserts, even in highly harsh environments such as pools of crude petroleum (Imms, 1964). Insects are undoubtedly the most adaptable form of life as their total numbers far exceed that of any other animal category. The majority of insects are directly important to humans and the environment. For example, several insect species are predators or parasitoids on other harmful pests, others are pollinators, decomposers of organic matter or producers of valuable products such as honey or silk. Some can be used to produce pharmacologically active compounds such as venoms or antibodies. Less than 0.5 percentage of the total number of the known insect species are considered pests, and only a few of these can be a serious menace to people.

Insect pests inflict damage to humans, farm animals and crops. Insect pests have been defined by Williams (1947) as any insect in the wrong place. Depending on the structure of the ecosystem in a given area and man's view point, a certain insect might or might not be considered a pest. Some insects can constitute a major threat to entire countries or a group of nations. One prominent example is the tsetse fly that puts about 100 million people and 60 million head of cattle at risk in sub-Saharan Africa due to the transmission of trypanosomiasis (ICIPE, 1997).

Herbivorous insects are said to be responsible for destroying one fifth of the world's total crop production annually. One major reason why there are pests is the creation of man-manipulated habitats, that is, agroecosystems that fulfil man's needs, where crops are selected for their large size, high yield, nutritious value, and clustered in a confined area. This does not only satisfy man's demand, but provides a highly conducive environment for herbivorous insects at the same time. In the process of artificially selecting suitable crops for human consumption, highly susceptible plants for infestation by insects are also selected. Many of the crop varieties that were developed during the past 30 years produced high yields, but, they also had poor storage characteristics (Kerin, 1994). Insect pests are capable of evolving to biotypes that can adapt to new situations, for example, overcome the effect of toxic materials or bypass natural or artificial plant resistant, which further confounds the problem (Roush and McKenzie, 1987).

Provision of food has always been a challenge facing mankind. A major cornerstone in this challenge is the competition from insect pests. Particularly in the tropics and sub-tropics, where the climate provides a highly favourable environment for a wide range of insects, massive efforts are required to suppress population densities of the different pests in order to achieve an adequate supply of food. In the developing countries, the problem of competition from insect pests is further complicated with a rapid annual increase in the human population (2.5-3.0 percentage) in comparison to a 1.0 percentage increase in food production. Taking into consideration sudden problems caused by drought in places such as Africa, considerable losses of agricultural products add a serious burden to people's daily life.

The introduction of alien pests into new habitats due to the global increase of trade and transport causes another dilemma. When a pest is carried to a new geographical area, its natural enemies that keep it in check in its aboriginal home are normally left behind. This situation, in most cases, may lead to critical complications. One major example is the introduction of the spotted stemborer, *Chilo partellus* Swinhoe, into Africa coming from Asia early this century, that is now responsible for significant losses in maize and sorghum in many parts of Eastern and Southern Africa. The exotic pest may have also led to partial displacement of the native African stemborers such as *Sesamia calamistis* Hampson, *Chilo orichalcociliellus* Strand and *Busseola fusca* (Fuller) (Overholt *et al*., 1994; Kfir, 1997). Recent estimates of yield losses due to stemborers alone in sub-Saharan Africa are in the neighbourhood of 20-40 percentage of the potential yield (Youdeowei, 1989; Seshu Reddy and Walker, 1990). These losses indicate the importance of stemborers as a limiting factor affecting crop productivity in Africa.

Prostephanus truncatus (Horn) is another exotic storage pest native to Mexico. It has recently been introduced to Africa (McFarlane, 1988; Pike *et al*., 1992), where it is currently a more destructive pest of stored maize and cassava than in its native Central America (Dick, 1988). *P. truncatus* attacks maize before and after harvest. Adults bore into the maize cob causing severe damage and weight loss. In Tanzania, maize losses of up to 35 percentage may occur due to *P. truncatus* in 5-6 months if improperly stored (Mallya, 1992), and up to 60 percentage after nine months of storage (Keil, 1988); a situation that may result in a serious famine.

Subsistence grain production is essential for the growing population of Africa. Maize is the main staple food in sub-Saharan Africa. An area of 20.7 million hectares is planted to maize in the whole of the African continent, with an average annual production of 29 million tons (Christopher *et al*., 1996). In sub-Saharan Africa, three quarters of the total production of maize is consumed as human food, which is also the case with other cereals such as sorghum and millet. The area planted by sorghum in Africa accounts for 21.8 million hectares with an average yield of 0.78 ton/ha, while 18.5 million hectares are planted with different types of millet (finger millet, pearl millet, presom and foxtail millet), yielding an annual average of 0.61 ton/ha (FAO & ICRISAT, 1996). Several factors are responsible for this considerably low level of production, of which insect pests are chiefly involved. In the Kenyan highlands, total losses due to pests in maize were estimated at 57 percentage, with insect pests being more important than diseases (Grisley, 1997). In Zimbabwe, grain damage of 92 percentage in stored maize was reported due to insect pests. Treatment with malathion reduced the damage by only 10 percentage (Mutiro *et al*., 1992). In Namibia, up to 30 percentage losses in pearl millet production can take place due to the bush cricket, *Acanthopolus discoidalis* (Wohlleber *et al*., 1996).

Root crops, such as cassava and potatoes, and pulses, which are legumes grown for their edible seeds, provide the basic source of carbohydrates and protein for people in many parts of the African continent. The area planted to cassava in sub-Saharan Africa is estimated to be 8.9 million hectare producing 72 million tons annually (Sengooba, 1994). Insect pests, in addition to fungal diseases, are responsible for 50 percentage damage in cassava (Yaninek,1994). Pulses, described as the poor man's food (Aykroyd & Doughty, 1982), are widely planted in west Africa. Cowpea, for example, is grown extensively for seeds, pods and leaves in about 15 African countries, among which Nigeria and Niger produce half of the world's total crop (Pandey & Westphal, 1989). Cowpeas are attacked by a complex of insect pests, particularly towards the end of the planting season. In storage, the bruchid, *Callosobruchus maculatus*, causes the major losses. Infestations of stored cowpeas can be as high as 90 percentage in markets and in village stores (Alebeek, 1996).

Almost 80 percentage of these food crops are produced by small scale farmers and stored on the farm (Wongo, 1996). Due to poor storage structures and conditions, severe losses in quality and quantity of stored food are inflicted annually. Quantitative assessment of losses is difficult because of the high variability in infestation from year to year, however, estimates from several countries in Africa indicate an intense impact of insect pests (see table 1). In Kenya, the National Food Policy Document reported up to 30 percentage destruction of harvested maize due to pests during storage and handling (Wongo, 1996). In West Africa, up to 100 percentage damage to cowpeas may happen in a few months after storage due to the infestation of *C. maculatus* (Lienard & Seck, 1994). Such high levels of losses continue to take place because of poor threshing, cleaning, drying and storing techniques.

1.1 Magnitude of the problem

After the crop is harvested, it undergoes several operations that, if improperly done, may result in serious losses (see Laubscher & Cairns, 1983; Giga, 1987; Jonsson & Kashweka, 1987; Gwinner *et al*., 1996). As a start, it should always be recognised that an intact grain is an essential item for successful storing. Cracked or broken grains provide an entry point for infestation by insects and moulds during storage. Damage to grains may happen due to improper application of post-harvest practices such as threshing, drying or transporting (see Rowley, 1984; Dadzie, 1994; Simone *et al*., 1994). Threshing, which is the removal of grain from its protective case, may inflict a degree of physical damage to the grains (Laubscher & Cairns, 1983; Swamy & Gowda, 1987; Wilson, 1987). Millet for example is sensitive to threshing (see Appert, 1987; UNIFEM, 1988), therefore it is stored unthreshed and pounded on a daily basis according to the farmer's needs. Wongo & Pedersen (1990) found that threshed sorghum grains were more susceptible to *Sitophilus oryzae* than unthreshed grains. Maize, specially in wet regions, is normally stored in its shucks, but with modern varieties shucks are removed. In this case, proper care should be taken and insect repellents or antifeedants should be applied.

Crop transportation is another process where losses are common. Physical damage, grain spilling or deterioration might occur, specially if transport is prolonged. However, such losses can be avoided through proper packing, loading and handling of the crop (see Youdeowei & Service, 1983; Gwinner *et al*.,1996)

Crop products are eventually stored for varied periods of time depending on market demand, size of production and the farmer's needs. Storage is the most important and critical post-harvest operation. Deterioration of the grain quality during storage can be due to improper storing conditions, which leads to contamination with fungi or insect infestation. A primary source of infestation of the stored crop is the field where the crop has grown. In many cases, infestation starts in the field. In the case of the potato tuber moth (*Phthorimaea operculella*), adult females lay eggs on the plant leaves early in the season before the crop is harvested. With cowpeas, only a 1-2 percentage initial field infestation by *C. maculatus* may result in 80 percentage of the pods attacked after 6-8 months in storage (Youdeowei, 1989). The problem can be more complex if the crop is planted or stored near by old granaries, which is the case with most of Africa's small scale farmers. The infestation can easily move to and from storage sites. Moreover, using the same bins year after year without proper hygiene, provides a continuous chain of infestation. Insects can hibernate or even continue to feed on wooden structures of the store or hide between holes and cracks in the walls. They can then reinfest the new crop in the same store and resume feeding.

Storing generally leads to a degree of quality change in the product due to seed's respiration, which depletes seed's nutrients over time (see Hodges, 1989; Piergiovanni *et al*., 1993; Kadlag *et al*.,1995). Combined with attack by insects and mould, rapid deterioration of the crop quality might occur. In case of whole cereal grains, a rise in temperature is expected due to respiration, which might also occur due to insect or fungal activity. Heating leads to moisture condensation in cool areas within the grain mass. This in turn encourages further fungal growth and insect infestation (see Appert, 1987; Imura & Sinha, 1989). The exact safe moisture contents varies slightly between the different grains, however, moisture should not exceed the range of 12-13 percentage for most cereals. For pulses, intact dry grains are relatively resistant to damage, but moist, broken, split or shelled pulses are highly sensitive to infestation. On the other hand, very dry pulses with a moisture content less than 11 percentage have a breakable seed coat that cracks easily (see Youdeowei & Service, 1983; Gwinner *et al*., 1996).

In most parts of sub-Saharan Africa, harvesting of maize and other cereals is done by hand. Farmers have to wait until the crop is sufficiently dry. Some farmers leave the plant standing in the field until it dries up. This, however, might not be adequate as the longer the plant stays in the field the riskier it gets. Infestation by post-harvest pests are mainly encouraged during this stage. In Zimbabwe, for example, four months may elapse after physiological maturity of maize and before harvesting and treating the crop, during which 9.1 percentage of potential yield is lost due to attack by pests (Mvumi *et al*., 1995). Alternatively, maize might be picked up when it is still in need for drying, specially in the rainy regions of the tropics. In this case, quick drying should take place as soon as the crop is harvested. In drier areas, getting rid of excess moisture may be much easier than in wet tropical regions.

Traditional methods usually provide cheap and feasible ways of post-harvest handling of the crops. Farmers adopt different methods for grain drying depending on the farmer's environment and socio-economic status. Sun drying, for example, is a widely practised method wherever there is enough sunshine and little rains. In this case, grains are spread on wide plastic sheets to isolate the crop from soil dampness, and to make it feasible to move the crop later after drying or in case of sudden rains. Continuous checking should be done on the stored crop to investigate the moisture content, presence of pests, moulds or deteriorating grains. However, farmers may use fire to dry the grains, specially in the rainy areas of the tropics where sun drying is not applicable. A more appropriate method is the use of "bush dryers", where air is heated up by burning wood and then circulated through metal tunnels. Grains are spread on grids on top of the tunnels. One disadvantage with this method is that temperature might not be well controlled. Caution should be maintained as abrupt or overdrying will cause loss of nutrients or germination capacity. Temperature should not exceed 43^0C for cereal seeds and 35^0C for legumes. Higher temperatures (up to 60^0C) can be used to dry cereals meant for consumption (see Gwinner *et al*., 1996).

A more controlled sun drying method is the use of solar dryers, where the product is spread on grids and placed inside a cylindrical metal tunnel (see Mbengue *et al*., 1987; Odogola, 1994). The tunnel is painted black to absorb heat and contains an opening from one side to let in air. A chimney is provided on the other end to serve as air and moisture outlet (see Ekechukwu & Norton, 1997). Inflow of air can be regulated through the entrance, thus adjusting air temperature inside the tunnel. Solar dryers are adequate devices, specially for smaller quantities of products, in which grains are fairly well protected against adverse weather conditions and the invasion of insect pests. Continuous improvements in the structure and utilisation of solar dryers are taking place in Africa (Bechis *et al*., 1997; Ekechukwu & Norton, 1997), however, the use of solar dryers does not seem to be as wide spread as other drying methods in Africa, probably due to the relatively high cost and their limited capacity. Solar dryers may not be applicable in highly humid or cloudy areas of the tropics (but see Asota, 1996; Ekechukwu & Norton, 1997).

1.2 Storage and Losses

1.2.1 Small scale storage structures

At a small farming scale, grains are stored traditionally in different styles of containers, depending on the farmer's socio-economic status and his environment (see Audette & Grolleaud, 1983). Structures used traditionally are often inexpensive and environmentally motivated. Subsistence stores may be made out of clay, thatch, mud, wood or stones (see Rukuni *et al*., 1988; Bani, 1991). Larger granaries, meant for storing large quantities for longer periods of time, may be built with more permanent structures, as in case of metal silos or wooden granaries with iron sheet roofs. Open storage is probably the most common system used traditionally in sub-Saharan Africa, specially in the humid areas, where the crop is harvested with high moisture contents and continues to dry in the store. Open structures can simply be wooden platforms on stakes or posts, on top of which the crop rests either in heaps or regular layers. A straw roof is usually provided to protect the crop from rains. Farmers may use fire underneath this structure for insect control and to provide further drying. An even simpler method is hanging the crops in frames or sheaves to tree branches, which is applicable for smaller quantities that would be rapidly consumed. Open storage provides natural ventilation and allows for further drying of the crop. It also discourages development of fungi due to continuous aeration. However, open storage does not provide adequate protection against insect pests or other animals such as birds and rodents (see Appert, 1987; Gwinner *et al*., 1996).

A more protected storage system, adequate for the semi-arid regions of Africa, is the use of "cribs" (see FAO, 1985; Appert, 1987). Cribs are wooden four-cornered structures with ventilated sides. The sides are covered with woven straws, grass stalks or wire netting materials and a thatch roof is provided on top. An elevated floor is made out of wooden branches and attached to the posts about 50 cm above ground. This structure proved to be excellent for drying maize in Nigeria, where it is made out of bamboo and used mainly for drying and storing maize cobs. It is also used in other humid regions of sub-Saharan Africa with considerable success.

In the dryer regions of Africa, where crops can be harvested with satisfactory low moisture contents, more closed types of granaries are used. Different sizes and types of such closed structures are widely spread in Africa, where they can be made out of mud, woven straws or a mixture of mud and chopped straws (see Figure 1). Farmers in the semi-arid zones of sub-Saharan Africa, such as Mauritania, Senegal, Mali, Niger and Chad, use a mixture of clay or mud and straw called "Banco" to build concealed granaries. Banco granaries can be four-cornered, spherical, with a straw roof containing a protecting lid, or in the shape of a cone with the tip pointing downwards and resting on a foundation of stones. Grains inside these banco granaries are well protected against rains and the invasion of insect pests. If the structure is well built and maintained, insect pests would find it very difficult to survive inside due to the lack of oxygen. Granaries made out of mud or clay provide a cool environment that keeps grains viable for germination. This structure is appropriate for dryer areas of Africa where sudden heavy rains are unlikely. However, Banco granaries require good maintenance such as filling cracks, which are common with mud structures, sealing holes or fissures and thorough cleaning.

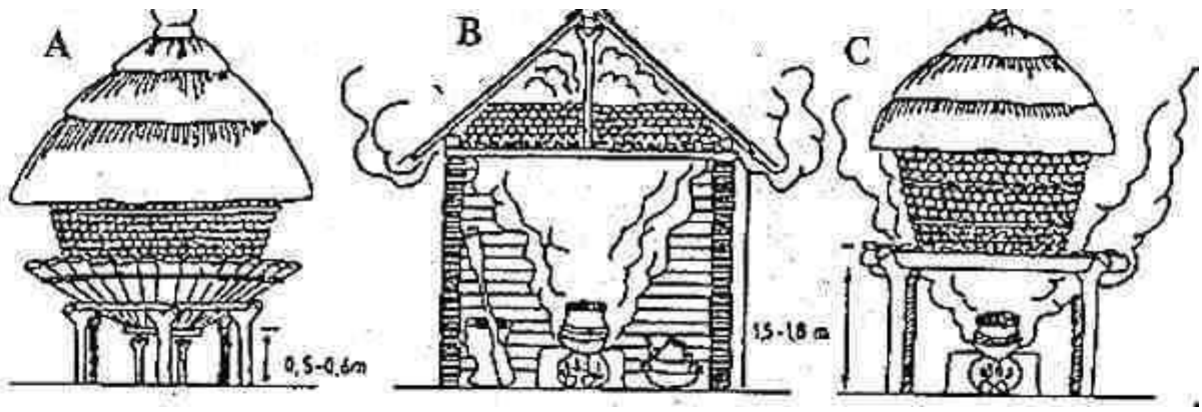

Figure 1: Traditional maize storage systems in the southern region of Togo (Pantenius, 1988) (A: noy-heated granary; B: Regularly heated in house storage; C: Irregularly heated granary)

In some parts of Africa, such as Morocco, Mauritania, Nigeria, Chad, Cameroon and Somalia, grains are stored underground (see Bartali *et al*., 1990; Bakhella *et al*., 1993; Lemessa & Handreck, 1995), however, it is not as widespread in the African continent as it is in India. In India, an underground pit, 2-2.5 meters in depth, is dug in soil and a fire may be lit to dry up the walls. Afterwards, bricks can be used to build a wall or otherwise walls are plastered with clay and the bottom is covered with chopped straws or husks. The pit is sealed from the top with a roof at or slightly above ground level. Underground storage provides excellent protection to the stored products specially in arid areas, however, it may also be applicable in rainy areas provided that the entry of both ground and rain water is prohibited through careful cementing and lining of the walls (see Mantovani *et al*., 1986; Smith & Sanders, 1987).

Smaller amounts of grains can be stored in different types of containers, calabashes, clay pots, sacks or woven baskets (see Kennedy & Devereau, 1994). Such containers allow for frequent consumption of the product on a daily or weekly basis. Baskets can be made out of local plant materials and may themselves be placed inside the granary or in the farmer's house. Jars made out of clay are also used to store beans or cowpeas, as in west Africa, where they are usually placed inside the farmer's house. Jars have a narrow opening and are hermetically sealed with a stone on top. Hermetic storage leads to depletion of oxygen and accumulation of carbon dioxide inside the container, which eventually lead to elimination of insect pests (see Mantovani *et al*.,1986).

Traditional storing systems can be satisfactory if built and maintained properly. Recently, farmers in sub-Saharan Africa started adopting newer storing systems. Concrete or metal silos, with capacities up to 5 tons of cereals, are now used in many parts of the continent among medium scale as well as large scale farmers. The use of plastic sacks, bag storage, prefabricated iron halls and flexible plastic silos are increasingly gaining ground among farmers for short-term storage (see Peterson & Simila, 1990; Compton *et al*., 1993; Bartali, 1994). Large warehouses and metal silos, run under state control, are common among co-operatives and traders. Centralised storing has emerged due to the change in the social and economic structures of the farm community. Centralised stores can be large metal constructions that may contain up to 3000 tons of produce. Though the adoption of bulk storage has led to a significant decrease in the amount of food stored by small scale farmers for emergencies, it does form an important function in sustaining sufficient food supply. Bag storage in large warehouses is a suitable system for bulk storage in the tropics and sub-tropics (see Carvalho *et al*., 1994; Cabrera & Lansakara, 1995)

1.2.2 Warehouses

Warehouses are practical and appropriate structures for storing and protecting food crops (see Cabrera & Lansakara, 1995; Gwinner *et al*., 1996). Stored crops can be easily maintained and treated, transported to and from the warehouse and regularly checked for insect or fungal infestation. Good and effective warehouses are simple four-cornered buildings with ample ventilation. It is always preferable to build a concrete floor one meter above the ground level to guarantee adequate isolation of ground moisture or water flooding. Concrete walls are the most suitable if properly built with no cracks or holes to discourage insects. Aluminium sheets provide adequate roofing and are better used than corrugated iron to avoid raising of temperature. Appropriate and controlled ventilation is essential for successful storage in warehouses. Lower and upper ventilation openings for inlet and outlet of air should be fitted with wire mesh or grids , but with the possibility for sealing to allow for secure pesticide fumigation. A well designed and maintained drainage system is important for preventing rain water from affecting the stored produce (For more details on warehouse structures see Bisbrown, 1992).

Sanitation in stores is a key factor for preserving products in good condition (see Suss & Locatelli, 1993; Rotundo *et al*., 1995). Sanitation is a simple practice that can save the product from losses due to infestation. Sanitation starts with the removal of any unnecessary objects from the store. Thorough cleanliness of the store through sweeping, removal of left overs and prompt burning the trash is essential before receiving in a new lot. Clearing the surroundings is a recommended practice, in which grasses, shrubs and any kind of vegetation around the building should be cut down thoroughly. The produce should be checked on a regular basis and the presence of any insect pests, rodent debris, damaged cobs or rotten grains should be recorded and dealt with accordingly (see FAO, 1985; Cruz & Diop, 1989; Vinuela *et al*., 1993).

1.3 Insect damage

Insect pests inflict their damage on stored products mainly by direct feeding. Some species feed on the endosperm causing loss of weight and quality, while other species feed on the germ, resulting in poor seed germination and less viability (Malek & Parveen, 1989; Santos *et al*., 1990). Thus, due to damage done by insects, grains lose value for marketing, consumption or planting. Most storage pests are able to increase in numbers drastically within a relatively short time. At an early stage of development, population growth takes the "exponential" form, where the number of insects at a given time can be expressed by this equation: $N_t = N_0 e^{rt}$, where N_t is the number of insects at time t, N_0 is the original number of insects and r is the rate of intrinsic increase of the population (Figure 2). However, this pattern of growth would eventually reach an upper plateau due to depletion of food and intraspecific competition (Figure 3). In that case, the number of insects at any given time can be expressed by the equation:

$N_t = K/(1+((K - N_0)/N_0)\, e^{-rt})$

where K is the maximum number of insects that the environment can support, which is also known as the "carrying capacity" of the environment. In grain stores, K is not constant and will decrease as the food is consumed. Eventually, the insect population will start to decline due to the decrease in food availability and competition among individuals, which is when a proportion of insects will have to migrate and search for other food sources (Figure 4).

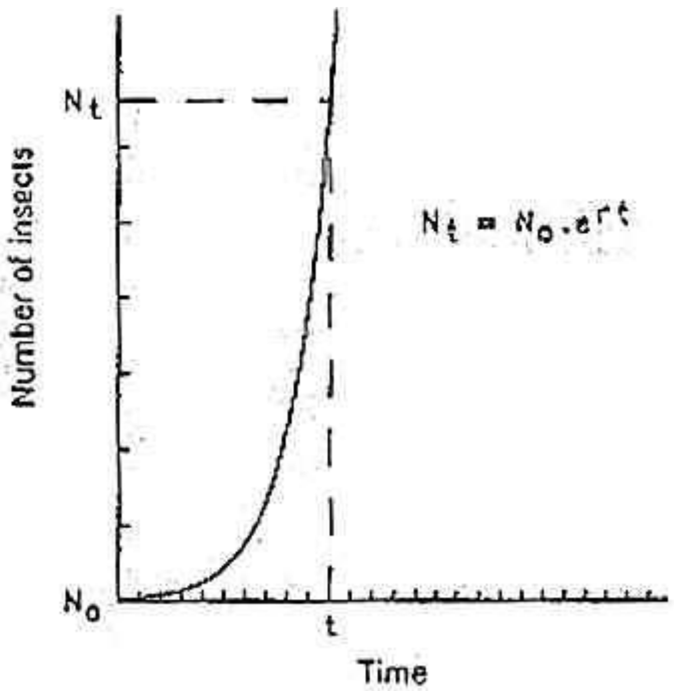

Figure 2: The theoretical exponential increase of an insect population (Haines, 1991)

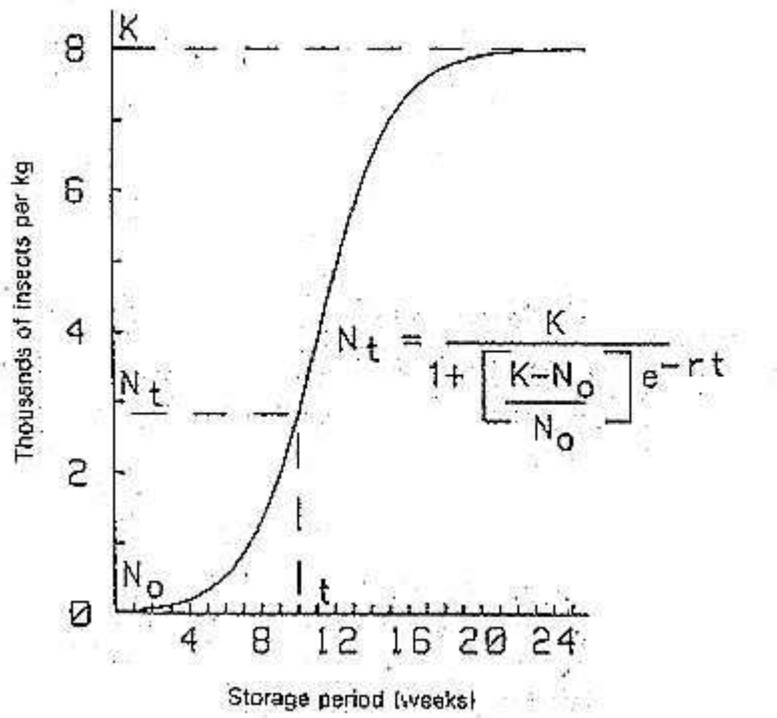

Figure 3: The logistic growth of an insect population in a restricted environment (Haines, 1991)

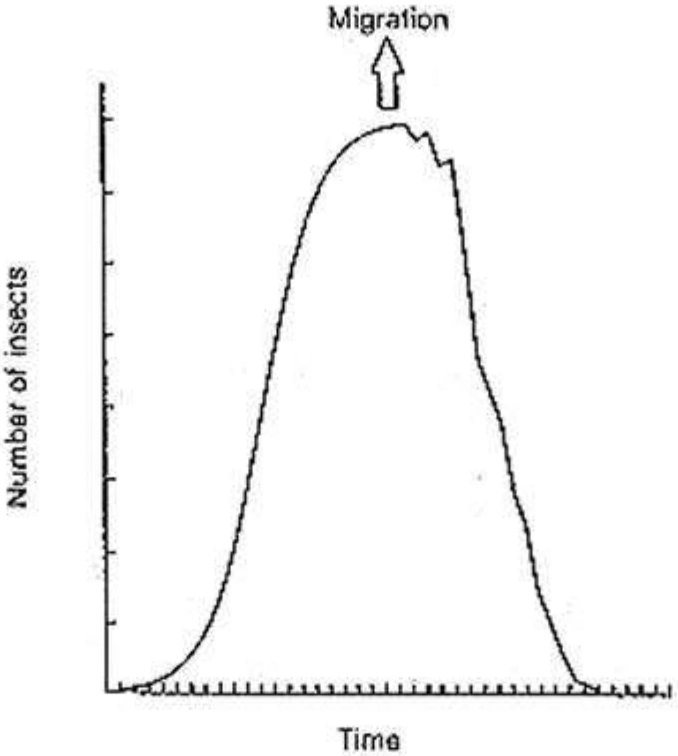

Figure 4: Insect population growth in a restricted environment without food replenishment (Haines, 1991)

In addition to direct consumption of the product, insect pests contaminate their feeding media through excretion, moulting, dead bodies and their own existence in the product, which is not commercially desirable. Damage done by insect pests encourages infection with bacterial and fungal diseases through transmission of their spores (Cravedi & Quaroni, 1982; Ekundayo, 1988; See also Dunkel, 1988). The presence of insects also raises the product temperature, due to their feeding activity, resulting in "hot spots" (see Appert, 1987; Mills, 1989). These spots in turn lead to concentrating of humidity within the product, thus stimulating seed deterioration and further fungal activity. There are a wealth of studies examining the effect of insect pests on grain contents. In Brazil, for example, Santos *et al*. (1990) showed that the presence of *Sitophilus zeamais* and *Sitotroga cerealella* in maize grains led to a reduction in germination with increasing developmental stage of the insects, from 13 percentage at the egg stage for *Sitophilus zeamais* and 10.9 percentage for *Sitotroga cerealella*, to 93 percentage and 85 percentage at the adult stage for *S. zeamais* and *S. cerealella* respectively. In India, Sudesh *et al*. (1996 b) found that infestation of wheat, maize and sorghum grains with single or mixed populations of *Trogoderma granarium* and *Rhyzopertha dominica* resulted in substantial reductions in the contents of total lipids, phospholipids, galactolipids, and polar and nonpolar lipids, while Jood *et al*., (1995) recorded a significant decrease in essential amino acids in the same crops due to mixed infestation with the same two pests, with maximum reduction found in methionine, isoleucine and lysine. Similarly, Kumar *et al*., (1996) recorded a substantial reduction in starch in parboiled cassava chips due to infestation with *Sitophilus oryzae* and *Rhyzopertha dominica* as compared to the uninfested chips. In Nigeria, Okiwelu *et al*. (1987) recorded high level of moisture, combined with a decrease in germination ability of maize due to infestation by *Sitophilus zeamais*, while Mbata (1994) showed that infestation of bambarra groundnuts (*Vigna subterranea*) with *Callosobruchus subinnotatus* reduced seed viability and increased free fatty acids and peroxides, which are indices used in measuring biochemical deterioration.

2. Major insect pests of stored foods

Two major groups of insects harbour the mostly economically important post-harvest insect pests: Coleoptera (beetles) and Lepidoptera (moths and butterflies). Several Coleopteran and Lepidopteran species attack crops both in the field and in store. Crop damage by Lepidoptera is only done by the larvae. Several lepidopteran larvae entangle the feeding media through silky secretion which turns products into entwined lumps. In the case of Coleoptera, both larvae and adults often feed on the crop and the two stages are responsible for the damage. Post-harvest insect pests may be primary, i.e. able to attack intact grains such as the genus *Sitophilus*, while others are secondary pests, attacking already damaged grains or grain products such as the genus *Tribolium*. The following is a list of the most common post-harvest and storage pests, their biology, distribution and common host plants.

2.1 Coleoptera

The order Coleoptera is the largest order of insects and contains the most common and important stored product pests. Adults have their forewings modified as hard elytra. Beetles inhabit a wide variety of habitats and can be found almost everywhere. Those associated with stored products exhibit different behavioural types; some are primary and secondary pests feeding directly on the product, others are general scavengers, fungus feeders, wood borers or predators of other insects. arvae lack the presence of prolegs (abdominal legs) and only possess true legs on the three thoracic segments. Larvae of a few species may also lack true legs, e.g. *Sitophilus* spp.

2.1.1 Curculionidae (Snout Beetles)

This is a large group of beetles that contains some of the most serious crop and stored grain pests. Members of this family are characterised by the form of the snout (rostrum) which is

elongated in most species. This family contains the most destructive stored grains pests in the world.
The Rice Weevil: *Sitophilus oryzae* (L.) (=*Calandra oryzae* L.)

Figure 6:
Rice weevil
The Maize Weevil: *Sitophilus zeamais* Motsch. (=*Calandra zeamais* Motsch.)

Figure 12:
Maize Weevil
The Granary Weevil: *Sitophilus granarius* (L.)
The first two species are major primary pests that have a virtually cosmopolitan distribution throughout the warmer parts of the world. The rice weevil (*S. oryzae)* mainly attacks rice and wheat in stores, while *S. zeamais* is a serious primary pest of stored maize. However, both species are able to develop on all cereals, dried cassava and other processed food products. The two species are morphologically identical. In Europe, the two species are replaced by the granary weevil, *S. granarius*, which is wingless and can be distinguished by the sculpturing on the prothorax and elytera.
Natural history:
The life cycle and damage caused by both *S. oryzae* and *S. zeamais* are similar. However, *S. zeamais* is a little larger (5 mm in length) and a very active flier. Infestation usually starts in the field and later continues in the store. Both species are capable of inhibiting reserved breeding grounds near the threshing floors that are normally full of plant residues, where the population builds up in before moving to granaries. Adult females chew grains creating a small hole in which they lay eggs and then seal the hole with a secretion. The optimum temperature for oviposition is around 25^{o}C and at grain moisture contents of over 10 percentage (Brich, 1944). Larvae tunnel in grains and are responsible for most of the damage. pupation takes place inside the grain and adults chew their way out through the outer layer of the grain. Adults live for 5-6 months depending on the temperature and humidity of grains (see Kuschel, 1961; Giles, 1969; Mound, 1989).
S. oryzae adult females can lay more than 500 eggs during their lifetime. The optimal temperature for development is 30^{0}C with maximum oviposition taking place at 18 percentage humidity. The rice weevil can live without food for 6-32 days depending on temperature. This species is highly affected by changes in temperature; all stages die in about a week at 0^{0}C. On the other hand, *S. zeamais* tolerates lower temperatures than *S. oryzae* and can live for 37 days at 0^{0}C (see Floyd, & Newsom, 1959; Stoyanova, 1984; Zewar,1993).
Natural history:
The granary weevil, *S. granarius*, lives for one full year at 20-25^{0}C and a relative humidity of about 15 percentage. Biology of this species is similar to the other two species, but it is unable to fly, thus restricted to the store (see Dobie & Kilminster,1978; Stein, 1994). This species prefers softer grains such as wheat, rye and barley, as food and habitat. In addition, *S.*

granarius has a high resistance to low temperatures; adults can stay alive for up to two months at -5^{0}C. Insects can be controlled if exposed to 50^{0}C for 35 minutes which will kill all stages (see Pradzynska, 1995). Buchi (1989) showed that *S. oryzae* is displacing *S. granarius* in Switzerland.

2.1.2 Tenebrionidae (Darkling Beetles)

This is a large and varied group of insects that contains more than 10,000 species of which about 100 are associated with stored products. Most of the tenebrionids are black or dark brown in colour and mainly phytophagous. Adults are characterised by the tarsi of the hind leg with only four segments. Infestation by these beetles results in an unappealing smell due to the secretion of benzoquinones from abdominal glands. The following tenebrionids are serious secondary pests of stored grains and flour.
The Red-Rust Flour Beetle: *Tribolium castaneum* Herbst.

Figure 9:
Red-Rust Flour Beetle

The Confused Flour Beetle: *Tribolium confusum* J. du Val

These two species are probably the most common secondary pests of all plant commodities in store throughout the world. Several other species of *Tribolium* are occasional minor pests and can be found in almost every store containing infested cereals or cereal products, specially in tropical and sub-tropical climates. Both species attack maize, wheat, flour and other foodstuffs, but *T. confusum* does not seem to be as common as *T. castaneum* in tropical climates (see Hill, 1987; Mills & White, 1994). Members of genus *Tribolium* are known to produce toxic quinones which contaminate flour and flour products (Gorham, 1989). Damage is done by both larvae and adults specially to broken or damaged grains.

Natural history:

T. castaneum adult females lay small, cylindrical, white eggs scattered in the product. At an optimum temperature of 32.5^{0}C, females lay up to 11 eggs daily. Larvae are yellowish with a pale brown head, and they live inside grains until pupation. Adults are about 3-4 mm long and can live for a year or more. Females are highly fecund and able to lay a maximum of 1000 eggs during a lifetime, with 40^{0}C and 22^{0}C as upper and lower limits for development. This species is also highly tolerable to humidity as low as 11 percentage. Adults are highly adapted to feed on a very wide range of commodities and perfect colonizers of new habitats. In tropical conditions, this species is dominant to *T. confusum* (see Howe, 1962; Dawson, 1977).

The confused flour beetle, *T. confusum*, is often confused with *T. castaneum* but they can be separated using the last three segments of the antenna which are much larger than the rest in *T. castaneum* and forming a club, while the last five segments in *T. confusum* gradually enlarge towards the tip. Just like *T. castaneum*, the confused flour beetle develops in crushed grain products and a constant inhabitant of flour mills specially in the temperate regions of the world. In contrast to *T. castaneum*, this species is not able to fly, but has a long life span that can reach three years under moderate climatic conditions (25-30^{0}C) (see Sokoloff, 1972; 1974; 1977).

2.1.3 The Yellow Mealworm Beetle: *Tenebrio molitor* L.
Natural History:

Tenebrio beetles are black or dark brown and they feed as larvae and adults on grain products. *T. molitor* is an important post-harvest pest and occurs spread all over the world. Adults are elongate, 16 mm long, and active fliers. Females can lay up to 600 eggs during its lifetime. Larvae firstly eat the germs of stored grains and can feed on a wide variety of plant products such as ground grains, flour, tobacco and foodstuffs. Larvae are very voracious and highly resistant to low temperature; they can remain alive for 80 days at -5^{0}C.

Other tenebrionids are less common polyphagous pests around the globe such as *T. destructor*, *T. madens* and *Palorus depressus*.

2.1.4 Bostrichidae (Branch and Twig Borers)

Members of this family are elongate with the head bent down ventrally to the thorax. Adults are characterised by rasp-like hooks on the pronotum. Most of the species are borers in wood or roots. Wood boring activities of these beetles may weaken timbers or wooden walls of the stores. This family contains two serious stored grain pests:

The Lesser Grain Borer: *Rhizopertha dominica* (Fabricius)

The lesser grain borer (*R. dominica*) attacks a wide range of stored cereals. It can be found attacking cassava, flour and other cereal products and is also able to attack rough rice grains. The pest originated from South America, but is now found in all the warmer parts of the world. This species is a serious pest in Australia, from where it was carried to the USA and other parts of the world during World War I. Adults of this species are tiny dark beetles, 2-3 mm in length, and are very voracious with a long life span. Females may continue to lay eggs for four months and are able to lay up to 500 eggs at 34^{0}C. They feed externally on grains and lay eggs on their surface. Larvae feed either externally or inside the grain and pupation takes place within the eaten grain. Larval development is relatively faster when fed on whole grains than on flour. Both adults and larvae eat the endosperm leaving powdered grains. This dust can accumulate on the walls of the warehouses and it is a sign of high infestation. Though are not common on pulses, adults are able to breed in grains that are too dry for fast development of *Sitophilus*. At 34^{0}C, development is possible on grains with moisture contents as low as 9 percentage, and they can daily destroy grains equal to their body weight (see Birch, 1945; Fisher, 1950; Aitken, 1975).

Figure 5:
Lesser Grain Borer

2.1.5 The Larger Grain Borer: *Prostephanus truncatus* (Horn)

The larger grain borer is a primary pest, often attacking maize in the field towards the end of the season, then continuing in the store. *P. truncatus* is a serious pest of maize in Central America and many parts of Africa. It was first reported in East Africa in 1981 and in 1984 in West Africa. Since then, it has spread rapidly in the African continent where it has become a major pest of stored maize and dried cassava. In Togo, soon after the discovery of *P. truncatus*, mean losses of 30.2 percentage were reported on stored maize six months after storage (Pantenius, 1988). Stored dried cassava is also known to become heavily infested by *P. truncatus*, which may lead to cross infestation of maize. Hodges *et al*. (1985) reported 70 percentage loss in dried cassava roots after four months of storage due to this species.

Figure 10:
Larger Grain Borer

Figure 11:
Larger Grain Borer

Adults of *P. truncatus* bore in maize grains and produce large quantities of dust, in which their larvae seem to feed and pupate. This species proved to be highly tolerable to low moisture contents in grains. Field studies in Tanzania recorded heavy infestation in maize at a moisture content as low as 9 percentage. The introduction of this pest in Africa has influenced the economy of several countries, specially those depending on exporting of maize. Many countries now refuse to import maize from areas infested with the larger grain borer (see Boeye *et al*., 1992).

2.1.6 Bruchidae (Seed Beetles)

Most bruchids are short, stout-bodied beetles with a short forewing not reaching the tip of the abdomen. Adults are characterised by their compact hairy bodies and relatively long antennae. Larvae of most species feed inside seeds and some develop in stored dry grains or legumes. All bruchids are phytophagous with most species able to avoid feeding on seed covers that contain toxins. This family contains several important field and stored crop pests.

2.1.7 The Cowpea Weevil: *Callosobruchus maculatus* (Fabricius)

This is an important pest that mainly attacks beans of various species, and can alternatively attack other pulse crops (see Lienard & Seck, 1994). This species originated in Africa but is now found all over the tropics and sub-tropics. Adults are 2-4 mm, brownish with black markings. They have a short life span of about 12 days and do not feed. Two forms of this species have been identified; the active (flying) form and the flightless form. The flying form disperses and colonises cowpea fields. Adult females lay about 100 eggs glued to the seed surface or to pods. Larvae tunnel inside the seed where the entire development takes place. In the store, the normal form continues to reproduce until the end of the storage season. The flying form appears again in response to disperses to new locations. This species causes major problems in Nigeria and Niger, where most of Africa's cowpeas are produced (see Alebeek, 1996). Other species such as *C. rhodesianus* and *C. subinnotatus* may also be important in some parts of Eastern and Central Africa (see Gillon *et al*., 1992; Giga *et al*.,1993).

2.1.8 The American Bean Weevil: *Acanthoscelides obtectus* Say (*Bruchus obtectus* Say).

Figure 7:
American Bean Weevil

This species is widely distributed in Africa, Central and South America, New Zealand, USA and Southern Europe. *A. obtectus* exhibits high tolerance to varied degrees of temperature, thus, it is found in cool highland areas as well as the warmer parts of the tropics. It mainly attacks beans of various types and other pulse crops. Adults are grey and oblong in shape, with the body covered by yellowish green hairs. Females are almost twice as large as males. Infestation starts in the field when females lay eggs on the mature beans in plant pods. Larvae are tiny with strong mandibles and feed inside the seeds where life cycle is completed. Adults exit the seed through round holes about 2 mm in diameter (see Wendt, 1992).

2.1.9 The Groundnut Borer (Seed Beetle): *Caryedon serratus* (Olivier) = (*C. gonagra* (F)).
Natural history:

This species is common in West Africa and parts of South Eastern Asia where it probably originated. Adults are 4-7 mm in length with distinct serrate antennae. *C. serratus* attacks mainly groundnuts and other legumes, pods and seeds of Acacia tress and tamarind. Adult females glue their eggs on groundnut seeds soon after harvest. Larvae bore inside seeds making a large hole in the cotyledon. Pupation may take place inside or outside the kernel in paper-like cocoon attached to the pod. *C. serratus* is a serious pest of stored groundnuts in West Africa (see Delobel 1995; Satya *et al*, 1996).

Several other bruchids are known as post-harvest pests in different geographical areas of the world:

Species	**Remarks**
Callosobruchus chinensis (Linnaeus)	Originated in tropical Asia, but is currently distributed all over the tropics and sub-tropics. It attacks chickpeas, cowpeas and green grams. Life cycle and damage is very similar to *C. maculatus* (see Parajulee *et al*., 1989).
Callosobruchus subinnotatus (Pic)	Formerly described as a strain of *C. maculatus*. It is found in West Africa where it attacks "Bambarra groundnuts" (see Mbata, 1994).
Callosobruchus theobromae (Linnaeus)	A pest of pigeon pea in India and was recorded in a groundnut field in Nigeria.
Bruchidius atrolineatus (Pic)	Mainly a field pest of cowpeas but eggs and larvae are taken to storage after harvest (see Monge *et al*., 1988). (Huignard *et al*., 1985) recorded 90% pods infestation from Niger in West Africa.
Bruchus atomarius L.	Distributed in Europe and parts of Asia. Attacks beans, peas and lentils.
Bruchus lentis Frol	A monophagous species that occurs in some warmer parts of the world. This species infests lentil seeds in stores (see Mozos, 1992).
Bruchus pisorum L.	Reported from Europe, Canada, South East Asia and former USSR. A monophagous species that attacks ripe plant pod and can only develop on peas (see Almasi, 1990).
Bruchus rufipes Herbst	Distributed in central and southern Europe, Asia and south Africa. Attacks vetch seeds in which they develop (see Bakoyannis, 1988).
Bruchus dentipes Baudi	This species occurs in bean cultivating area. Infests seeds of broad beans and other species of the genus *Vicia* (see Bakoyannis, 1988; Wendt, 1992).

2.1.10 Cucujidae (Flat Bark Beetles)

Members of this family are small flattened beetles, mostly found under the bark of trees or in tunnels made by other beetles. This family contains one common pest of stored grains.

2.1.11 The Red Rust Grain Beetle: *Cryptolestes ferrugineus* (Stephens)

Adults of this species are oblong flattened small beetles (1.5-2 mm long), with the head and prothorax relatively big and conspicuous. *C. ferrugineus* is a widespread secondary pest of stored grains, specially in the humid tropics. The genus *Cryptolestes* was reported to be of economic importance towards the end of the maize storage season in Togo (Pantenius, 1988). However, it might not be as serious as other pests in stores, often following an infestation by other insects. It usually attacks the germs of broken or cracked grains thus reducing germination. Other species such as *C. pusillus* (Schonherr) and *C. pusilloides* (Steel and Howe) are common in humid areas of the tropics (see Banks, 1979).

Silvanidae

This family was formerly included in Cucujidae. It includes two important species:

The Saw-toothed Grain Beetle: *Oryzaephilus surinamensis* (L), recognized by the toothed lateral margins of the pronotum.

The Merchant Grain Beetle: *Oryzaephilus mercator* (Fauvel), which is found in association with *O. surinamensis*.

Both species are virtually cosmopolitan and they infest a wide variety of stored grains, processed foodstuff and other food products. They are mainly secondary on stored products following more destructive primary pests. However, *O. surinamensis* prefers cereal products while *O. mercator* is more frequent on oil-seed products and more temperature sensitive. They enter damaged grains and feed specially on the germ. Optimum conditions for development are between 30- 35^{0}C and 70-90 percentage relative humidity.

Natural history:

Adults are 3 mm flattened narrow winged beetles but they rarely fly. Females lay their eggs loosely within the stored products. Larvae are free living and start by feeding on the embryo and the endosperm. They require 60-90 percentage humidity for optimal development, and neither species cannot develop or breed at temperatures less than 19^{0}C. All stages die in ten minutes if exposed to 55^{0}C (see Howe, 1956; Halstead, 1980).

2.1.12 Dermestidae (Skin Beetles)

Members of this family are ovoid in shape with hairy or sometimes scaly bodies. Larvae are very hairy. When stores are infested, these setae may be seriously hazardous if inhaled by workers. This family contains a number of very destructive and economically important species. One of the most serious stored product pests that belongs to this family is the Khapra Beetle: *Trogoderma granarium* Everts. Apparently the only phytophagous species in the genus *Trogoderma*. A native of India, the Khapra beetle is now found in most parts of the world specially hot and dry areas. Adults are oval, red brown insects with a dark thorax. Adult females may lay up to 120 eggs within the stored products. Larvae are considered primary pests as they attack undamaged grains and seeds and bore into stored pulses. They are highly mobile, and in the absence of food they enter a diapause that might last for more than two years, in which they can be highly resistant to the application of pesticides or fumigation. Adults are 3-4 mm long, dark wingless beetles that do not feed. Populations of this pest build up rapidly, specially in the hot humid tropics. This species was apparently eradicated in the United States and the former Soviet Union. It also seems to be absent from East and southern Africa (see Banks, 1977; Rebolledo & Arroyo, 1995; Sudesh *et al*., 1996 b).

2.1.13 Anobiidae

Anobiids are cylindrical pubescent beetles, 1-9 mm in length. The head is usually concealed from above by the hoodlike pronotum. Most anobiids live in dry vegetable materials or bore in wood, while others are fungus feeders. About 1000 species of Anobiidae are known, most of which are found in the tropics. The following are two widespread storage pests belonging to this family.

The Cigarette Beetle: *Lasioderma serricorne* (Fabricius) is a common pest of stored cereals, cocoa beans, tobacco, ground nut, peas, beans, flours and other foodstuffs. Originally from South America, it is now found in most of the warmer parts of the world. This species is notorious for attacking a wide range of intact cereal grains, pulse seeds and food stuffs.

Natural History:

Adults can breed anywhere at optimum temperatures of around 28-32^{0}C and a relative humidity of 75 percentage. Newly hatched larvae are very active and responsible for most of the damage. Adults are small brown beetles and the only damage they cause is due to their emergence holes. This pest can be controlled if exposed to temperatures below 18^{0}C. At 55^{0}C, all stages die in two hours (see Howe, 1957; Lefkovitch & Currie, 1967).

The Drug Store Beetle: *Stegobium paniceum* (Linnaeus) Another widespread pest that infests several cereals, but less common than *L. serricorne* in the tropics.

Natural history:

Adults are 3.5-4 mm in length, brown hairy beetles, and they do not feed. Females lay about 75 eggs and optimum conditions are 30^{0}C with 60-90 percentage relative humidity. Larvae are active feeders and they can be indiscriminate in their food choice, biscuits, macaroni, dry fruits and other products. This species is commonly found in the temperate areas of the world (see Lefovitch, 1967; Haines, 1991).

2.1.14 Trogossitidae (Bark Gnawing Beetles)

Trogosittids are brownish beetles. The Caddle (*Tenebroides mauritanicus* (L.)) is a common pest in granaries. Observed for the first time in Mauritius, it is now considered a cosmopolitan pest associated with a wide variety of commodities. *T. mauritanicus* attacks mainly cereals, oilseeds and their products. Both adults and larvae are highly tolerant to very cold conditions. Though larvae are known to predate upon other insects, both adults and larvae feed directly on stored food and larvae are able to tunnel in wooden walls of the store to create a pupation chamber (see Girish & Pingale, 1968; Aitken, 1975).

2.2 Lepidoptera

Lepidoptera is the second most important order of insects pests of stored products. Adults are active flyers with two pairs of scaly wings. Mouthparts of the adults are modified to suck plant nectar or other fluids and are not able to chew, while those of the larvae possess well-developed mandibles. Larvae are distinguished from beetle larvae by their pseudopods (false legs) on some of the abdominal segments. Lepidoptera larvae occur frequently in a wide range of habitats and are known for their silk-spinning activities that result in the additional loss of quality of stored products. Some species attack the product in both the field and store. Several moths are pests of the ripening crop and their larvae can be found in recently harvested stored grains. They either continue their attack for a short time in the store or form an entry point for further attack by true storage pests. The following families contain the most economically important lepidoptera post-harvest pests.

2.2.1 Pyralidae

Pyralidae is a large family, of which only a few species are stored product pests. Most pyralids are small and delicate moths. Members of this family exhibit a great deal of variation in appearance and habits. Larvae of all species possess glands which secrete silk with which they interlink food products as they move. This family is divided into a number of subfamilies, with the subfamily Phycitinae containing some of the most important stored grain pests. The best-known species in this subfamily are the following:

The Tropical Warehouse Moth: *Ephestia cautella* (Walker) = *Cadra cautella* Hb.

A very serious cosmopolitan stored product pest infesting a wide variety of hosts such as maize, wheat, and other grains in stores. It can also feed on dried fruits, beans, nuts, bananas and groundnuts.

Natural history:

Adult females lay up to 300 small round sticky eggs within the substrate and through holes in bags. Optimum conditions for larval development are 32-33^{0}C and 70 percentage relative humidity. Larvae feed on the seed germ and are fairly mobile within the produce. A considerable amount of damage results from webbing in the grain and on the surface of bags forming large lumps, therefore food is no longer fit for consumption once infested. Pupation takes place in crevices or between bags. Adult moths spread the infestation in the warehouse through egg laying. This pest is cosmopolitan in tropical and sub-tropical parts of the world (see Burges & Haskins, 1965; Hill, 1987; Mound, 1989; Bowditch & Madden, 1996).

The Warehouse Moth: *Ephestia elutella* (Hub.)

This species is a polyphagous pest that feeds on a vast variety of stored products such as dried cocoa beans, dried grains, pulses, nuts, tobacco, coconut and dried fruits. Infestation is mainly post-harvest.

Natural history:

The whole life cycle takes about 30 days at 30^{0}C and 70 percentage relative humidity. Most of the damage is due to contamination of food with exuviae, dead bodies and frass. Silk produced by larvae may be extensive. The warehouse moth is a world wide pest, but more abundant in the sub-tropics and temperate areas of the world. This pest shows high levels of resistance to several groups of pesticides (see Kamali & Taheri, 1985; Meng *et al*., 1990; Ryan, 1995).

The Mediterranean Flour Moth: *Ephestia kuehniella = Anagasta kuehniella* (Zeller).

Adults are similar to *E. cautella* but the body is relatively longer. A major pest of flour mills, its main habitats are flour and grout mills, corn milling plants, bakeries and any other place used for processing grains or preparing flour products. *E. kuehniella* occurs in most of the temperate and sub-tropical parts of the world, where average temperatures are around 20^0C-25^0C. Complete development requires about 74 days at 25^0C and 75 percentage relative humidity. Larvae entwine all the material on which they feed resulting in solid lumps of food particles, faeces and larval exuviae (see Jacob & Cox, 1977; Locatelli & Biglia, 1995).

Indian Meal Moth: *Plodia interpunctella* (Hübner)

This insect feeds mainly on meals and flours but can attack raisins, nuts and some pulses and whole cereals. The Indian meal moth is distributed all over the tropics and sub-tropics and in some parts of the temperate regions, specially in heated buildings. In the hot tropics, it is more abundant in cooler highland areas. Most of the damage occurs due to larval feeding on the germinal part of the grains. Damage also occurs through the contamination of foodstuff with dead larvae, frass and silk webbing.

Natural history:

Larvae feed in tubes they weave from silk secretions. Adult females stick about 200-400 eggs to the substrate or to the storage walls. Larvae develop and feed within the substrate and are sensitive to changes in temperature. The number of generations may be only two per year in Europe, but increases in the tropics to eight generations. Complete development takes about 27 days at 30^0C and 70 percentage relative humidity. Development ceases below 15^0C. All stages die at 55^0C in five hours (see Bell, 1975; Aitken, 1984; Locatelli & Biglia, 1995).

2.2.2 Gelechiidae

Gelechiidae is a large family of lepidoptera. All moths are small in size and several species are important plant pests. This family contains two serious post-harvest pests:

The Angoumois Grain Moth: *Sitotroga cerealella* (Olivier)

Figure 13:
Angoumois Grain Moth

This species is a serious primary pest that mainly attacks maize, wheat and sorghum, both in the field and in stores. A recent survey in southern Ethiopia revealed that this pest alone was responsible for 11.2 to 13.5 percentage weight loss in stored maize (Emana & Assefa, 1998). Infestation with *S. cerealella* starts in the field as females lay their eggs, singly or in groups, on grains. Larvae start feeding inside the grains, while still in the milk stage, and spend their entire life inside one grain. Thus, infestation is difficult to detect at this stage. Adults leave a conspicuous emergence hole at one end of the kernel. Infested grains are characterised by this circular window created by the larvae. Stored grains may be completely destroyed. Adults are active fliers, thus, they are able to infest neighbouring granaries, which is known as "cross-infestation". This pest is distributed throughout the warmer parts of the world (Africa, South and Latin America and southern Asia and Australia) (see Grewal & Atwal, 1969; Boldt, 1974)

The Potato Tuberworm: *Phthorimaea operculella* (Zeller) = (*Gnorimoschema operculella* (Zeller))

This species is a cosmopolitan pest of potatoes, tomatoes and eggplants. It attacks plants mainly in the field, but continues to feed on tubers in storage. Larvae mine in the leaves and stems and later bore into the tubers. Damage can be seen on leaves as silver spots due to the tunnelling larvae, or as tunnels in the plant stem.

Natural history:

Each female lays about 150-200 eggs and larvae tunnel through leaves and stem down to the tuber where pupation may take place. In the store, eggs are laid individually on the tubers near the eyes or on sprouts. *P. operculella* is an important pest in traditional potato stores in North Africa (Arx *et al*., 1987; Lagnaoui *et al*., 1996. See also Haines, 1977). High infestations of up to 50 percentage of tubers can take place in Yemen due to this pest (Kroschel, 1994).

2.2.3 Acaridae

The Flour Mite: Acarus siro

Mites are widely distributed tiny arthropods. They can live and develop on various plant in the field or indoors. Mites can be found in granaries, feed mixing plants, threshing floors, stacks of hay and straw, dead organic matter, soil or plant residues. Several species are predacious on other mites or insects. Mites are easily transmitted by virtue of their tiny size which allows them to be carried with dust, winds, insects, birds or rodents. About 30 mite species are known to be associated with stored products. Family Acaridae contains some damaging species, in which *Acarus siro* is probably the most important and commonly encountered mite in granaries. This mite is about 0.7 mm in length with an oval body. *A. siro* is a widely distributed polyphagous species that can be found on almost all products of plant or animal origin. It requires relatively high humidity (70 percentage), with humidities below 11 percentage being lethal to the mite. Temperatures below -15^{0}C for 24 hours kill all stages. At 60^{0}C, all stages die in 5 minutes.

Attacked grains lose nutrients and the ability to germinate due to feeding on the germ. Crushed bodies of *Acarus* cause coloration in flour that reduces the products value. Under normal conditions, this mite develops according to the following pattern: egg, larva, nymph I, nymph II, and adult. Some strains of *A. siro* may produce hypopus under favourable conditions. Hypopus is a diapause form that can be carried by rodents or insects to other storing places. However, this species does not seem to occur in most of the tropical lowlands, though it might sometimes infest grains in cooler upland areas (see Haines, 1991).

2.3 Fungal contamination and production of mycotoxins

Another important cause of grain deterioration is infection by fungal diseases. Just like infestation by insect pests, fungal infection mainly starts in the field and is later carried to the store. High relative humidity is a crucial factor for encouraging fungal infestation. Factors influencing the degree of humidity in the store can be a high moisture content in the product if it has not sufficiently dried after harvest, infestation with insect pests that results in hot spots and increased humidity, or improper storing technique that allows for contact with rain water or humidity condensation (see Ayertey & Ibitoye, 1987; Gwinner *et al*., 1996). Fungal infestation results in reduction of grain quality, change in colour, taste, smell, reduction in nutritional value, increase in free fatty acids (FFA) and reduction of germination ability (Dutta & Roy, 1987; Prasad *et al*., 1987; White & Jayas, 1993; Dharmaputra, 1997).

2.3.1 Fungal diseases

Fungal diseases may be highly hazardous as certain species of fungus produce mycotoxins (Christensen, 1975; Reddy & Nusrath, 1988; Latus *et al*., 1995; Miller, 1995), which are poisonous substances produced by moulds during their growth and development. Mycotoxins are highly stable compounds that cannot be destroyed through food processing, and the only way to avoid them is to prevent the fungal growth. The first recorded case of poisoning due to food contamination with fungal infestation was in the early 1930s, when 5000 farm horses died in Illinois, USA, due to a disease that was called the "mouldy corn disease". It occurred among farm animals that fed on maize left in the field after harvest (see Christensen & Kaufmann, 1969). Later in the mid 1930s, a plant pathologist in Minnesota, USA, isolated *Fusarium* sp. from maize infected by ear rot, and the extract gave similar disease symptoms on swine. A few years later in the former USSR, hundreds of people were affected by what was later described as "alimentary toxic aleukia" (see Taylor *et al*., 1996; Wild *et al*., 1996). People had eaten millet from plants overwintered in the field and gathered later in the spring. The grains were infected by different species of fungi, some of which produced potent toxins. In 1960, about 100,000 turkeys died in England of an unknown disease. Later a fungus identified as *Aspergillus flavus* was isolated from a suspected groundnut meal that was imported from Brazil. Extracts from this fungus confirmed the presence of a toxic substance that was given the name "aflatoxin" (see Christensen & Meronuck, 1986). This material has been extensively studied and proved to be highly toxic to man and farm animals. It is a liver toxin which can induce cancer in susceptible animals. Fungal growth can be very rapid as well as the production of aflatoxin, specially in tropical and sub-tropical countries, where environmental conditions are highly conducive (see Highley *et al*., 1994; Hennigen & Dick, 1995, Scudamore & Hetmanski,1995).

The fungus is widely distributed all over the world and has been found on all foodstuff and their products (Christensen & Kaufmann, 1969; Wareing, 1997). Several strains of *A. flavus* produce aflatoxin and can contaminate grains, pulses, cassava, oilseeds and other foodstuff. Factors during cereal storage can favour the development of the fungus and the production of aflatoxin (Cloud & Morey, 1980; Christensen & Sauer, 1982; Bhatti *et al*., 1990). A moisture content that is slightly above 9 percentage in groundnuts or around 16 percentage in cereals is enough to support the development of the fungus (Christensen & Meronuck, 1986; Paderes *et al*., 1997).

Aflatoxin has been found in sausages in Germany and other meat products. In the Philippines, aflatoxin was found in the majority of the samples of peanut butter in stores. Moreover, aflatoxin consumed by dairy cattle, though altered in their body, still remains toxic and shows up in the milk (see Christensen & Meronuck, 1986; Gwinner *et al*.,1996).

A. flavus can grow and produce aflatoxin in many kinds of plants and plant products. However, major agricultural crops in which aflatoxins can create a serious problem are groundnut, maize and cottonseeds, specially where crops are grown in warm and humid conditions (see Awuah & Kpodo, 1996; Bankole *et al*., 1996; Fufa & Urga, 1996). On the other hand, not all strains of *A. flavus* produce aflatoxins, some can even be used in the preparation of foods for human consumption. Several other *Aspergillus* species and other fungi in different genera are associated with stored products, some of which may produce other important mycotoxins (Jacobsen *et al*., 1995; Bottalico, 1997; Cvetnic & Pepeljnjak, 1997). The following is a list of the most common stored product fungus species.

Aspergillus candidus

This fungus is common in stored grains and their products where moisture content is at least 15-16 percentage. It is known to cause preliminary heating of stored grains. Its presence is an indication that a stored lot is contaminated with spoiled grains (see Jevtic *et al*., 1990; Bujari & Ershad, 1993; Awuah & Kpodo, 1996).

Aspergillus clavatus

This fungus is commonly found in soil and decaying plant materials. It requires a moisture contents of 23-25 percentage in cereal seeds and can grow at lower relative humidities on groundnut meal or copra (see Adisa, 1994; Famurewa *et al*., 1994; Lopez-Diaz & Flannigan, 1997).

Aspergillus fumigatus

This fungus occurs in decaying plant materials and requires relatively high temperature to develop (40^0C). It was reported to result in a high level of abortion in cattle feeding on contaminated food. *A. fumigatus* may also infect human lungs. However, this species requires a high relative humidity of 95-100 percentage to grow (see Darwish *et al*., 1991; Pandey & Prasad, 1993; Abdu *et al*., 1995).

Aspergillus parasiticus

An aflatoxin producing fungus which attacks maize, groundnuts and oilseeds (see Christensen & Meronuck, 1986; Le *et al*.,1995).

Aspergillus restrictus

This species is known to have a "restricted" growth. It is able to kill and discolour wheat germ at a narrow range of relative humidity of 13.8-14.3 percentage. *A. restrictus* is usually associated with rice weevils, but even when the insect pest is eliminated, the fungus will continue to grow. It is also associated with some grain infesting mites (see Jevtic *et al*.,1990; Silva *et al*.,1991; Udagawa, 1994).

Alternaria alternata

An important mycotoxin producing fungus that attacks rice, sorghum and soybeans (see Jevtic *et al*.,1990; Jacobsen *et al*., 1995; Hasan, 1996).

Fusarium graminearum

This species produces deoxynivalenol, which is a serious and acute human toxin. It also produces zearalenone. Both toxins are produced on maize, wheat and barley (see Wang *et al*., 1990; Sidorov *et al*., 1996; El-Sayed, 1997).

Fusarium moniliforme

This species commonly invades stems of maize plants and it is known to produce the mycotoxin, fumonisin. In high moisture conditions, *F. moniliforme* may be involved in rotting of the kernel. However, it requires a 22 percentage moisture contents to grow, thus, it does not cause serious problems in stores (see Lee *et al*., 1994; Tavares *et al*., 1995; Bacon & Hinton, 1996; Jin & Qiu, 1996).

Fusarium roseum

This species causes scab of wheat, barley and oats. Symptoms are the discoloration of seeds. It also causes "ear rot" in maize and may continue developing on maize left on the plants after harvest (see Biswal & Narain, 1991; Assemat *et al*., 1995; Adam, 1996).

Fusarium tricinctum

A mycotoxin producing fungus. Heavy infestations are common when maize is stored on the cobs in cribs (see Bao & Wang, 1991; Roinestad *et al*., 1994; Lin *et al*., 1994).

Helminthosporium spp.

Fungi belonging to this genus may cause seed infections in different cereals such as maize and rice (see Kedera *et al*., 1994).

Scopulariopsis spp.

A predominant fungus associated with black and white pepper, soybean flour and powdered milk (see Jevtic *et al*., 1990; El-kady & Youssef; 1993).

Penicillium verrucosum

This fungus infects barley and wheat. It produces ochratoxin, a mycotoxin that may lead to kidney damage in farm animals. Other certain species of *Penicillium* produce citrinin, an important mycotoxin that may lead to kidney damage in humans and farm animals. (see Skrinjar & Dimic, 1992; Mantle & McHugh, 1993).

2.3.2 Fungal infestation

Improper handling of crops during post-harvest processes can cause fungal infestation. Any damage to stored products increases their susceptibility to fungal contamination (see Tagliaferri *et al*., 1993). More importantly, insects activity can have a profound effect on the spread of fungal diseases through transmitting the spores and increasing the surface area susceptible to fungal infection, which eventually increases the production of mycotoxins. Dunkel (1988) indicated that some storage insect species are disseminators of storage fungi while others are exterminators; some storage fungi attract storage insects and promote their population increases while others repel and secrete toxins harmful to insects. Therefore, knowledge of basic biological relationships between insects and fungi in the stored grain ecosystem is crucial for their management. Several studies demonstrate the importance of insect pests as promoters or facilitators of fungal infection. In Nigeria, for example, Acholo *et al*. (1997) showed that the yam beetle, *Heteroligus meles*, which was the largest cause of damage to tubers, facilitated the spread of different *Fusarium* species and other less abundant fungi. None of the fungi was able to infect undamaged yams in the laboratory. In India, Pande & Mehrotra (1988) sampled wheat grains for *Sitophilus oryzae* and found that *A. flavus* was the most frequent species in their alimentary canals, followed by *A. candidus*, *A. sojae*, *A. fumigatus*, *Penicillium rugulosum* and *Cladosporium cladosporioides*. This indicates the possibility that *S. oryzae* transmits fungus spores from infested to healthy grains. In the USA, Beti *et al*. (1995) showed that maize kernels infested with *A. flavus*-contaminated *Sitophilus zeamais* weevils had higher levels of aflatoxin than *A. flavus*-inoculated maize without weevils. The presence of *S. zeamais* resulted in increased kernel moisture content which was positively correlated with aflatoxin contents. In addition, aflatoxin levels in infested maize increased with increasing numbers of *A. flavus*-contaminated *S. zeamais*, as *S. zeamais* carried spores both internally and externally on their exoskeleton.

In some crops, efforts to remove broken and discoloured seeds can effectively reduce the production of mycotoxins. However, this may not be practical for many products, especially when the fungal growth is internal and difficult to detect. In Thailand, an in-store drying system to control aflatoxin contamination in maize was developed. High moisture maize is dried to 18 or 19 percentage moisture content within 2 days and continuously dried to 14 percentage within 14 days. An airflow rate of 3.6-4.6 m3/min per m3 of maize is required to decrease moisture content from 19 to 12 percentage (Prachayawarakorn *et al*., 1996). In an experiment in India, cinnamon oil treatment of maize, in combination with sodium chloride, synergistically inhibited fungal infection, growth and aflatoxin production (Chatterjee, 1989).

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