APHLIS - AFRICAN POSTHARVEST LOSSES INFORMATION SYSTEM

- A TRANSNATIONAL NETWORK OF CEREAL GRAIN EXPERTS

Postharvest Quality Losses of Cereal Grains in Sub-Saharan Africa

September 2012

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Summary

This review of postharvest grain quality losses has been prepared for members of the APHLIS network and other users. APHLIS itself only offers estimates of cereal grain weight losses. These are useful in quantifying the national impact of losses, comparing losses between sites and years and relate directly to food security by enabling cereal balance estimations. Nevertheless, it is important to understand, and take into account, losses in quality. These are generally expressed in terms of lost income and probably have a more significant economic impact than weight losses. In one reported study of an informal market in Ghana, when weight loss was less than 5%, loss in maize value was found to be negligible; however at higher levels of weight loss, the value of quality loss was estimated to be about 3-5 times higher than weight loss. In Zambia, an estimate of lost farmer income showed that on average quality losses were twice the value of weight losses.

In APHLIS there is an overlap between losses of quantity and of quality, this is when quality losses are so bad that food is no longer fit for human consumption. At that point the grain is considered a 100% weight loss. Before this point, quality loss estimation is difficult because ultimately what is of concern is the loss of market opportunity/income. Although reduction in quality can be measured, i.e. a reduction from grade 1 to grade 2 could be determined by the parameters of a grading system, the relationship between quality and value is complex. This may be because markets are insufficiently quality conscious to distinguish between grades, or if grain is sold six months after harvest when grain is scarce then grade 2 may command a higher price than grade 1 did at harvest time. Consequently, in the past most loss estimation has focused on weight loss. Nevertheless, quality loss is an important consideration because it is a direct loss of value; it may also impact on food safety and nutrition. Quality loss is likely to be a very convenient means of monitoring loss reduction strategies, although if food security is a primary concern then weight loss will remain a key measure.

This review discusses the causes of quality loss in cereal grains, shows practical examples of quality loss factors in maize grading and presents ways that quality is determined and valued in formal and informal markets. The implications for APHLIS are that the weight losses it quotes are not necessarily the major component of economic losses, and that engagement with quality loss is essential if it is to help promote postharvest loss reduction. Quality loss of cereal grains in developing countries appears to be initiated mostly at farm-level, so the potential remedies for the problem are needed at the same level. Suggestions on suitable approaches to loss reduction for each step in postharvest handling and storage of cereal grains on-farm can be found on the APHLIS website on the main menu as ‘Postharvest loss reduction (tips)’.

There are clearly opportunities to use conventional grading systems to report on the postharvest performance of the smallholder; especially simple visual-scales that relate directly to these grades. APHLIS is in the process of developing a standardised approach to the collection of loss data that are needed to make postharvest loss estimates, and this will include suggestions for quality loss assessment. However, a particular challenge remains; how to put a monetary value on both quality and weight losses so that they can be combined into a single loss figure – the postharvest value losses

For a review of cereal grain weight loss, download ‘Postharvest weight losses’ from the APHLIS website (http://www.aphlis.net).

Postharvest quality losses of cereal grains in Sub-Saharan Africa

Contents

1. Introduction

This review provides the APHLIS network, and others involved in using the system, with a background to postharvest grain quality losses of African cereal grains. However, APHLIS itself gives estimates of <u>only</u> weight loss; the reasons for this are detailed below. Also available for download from the APHLIS website is a companion review dealing with the estimation of postharvest weight losses (Hodges, unpublished). For documentation of the APHLIS system you can download a report from the European Commission website (Rembold *et al*., 2011)

Losses of grain quality and of grain quantity are both defined as physical losses. One important difference between them is that losses of quality may lead to a failure to market grain or a failure to sell grain in a higher value market; such failures are called opportunity losses; they damage local and national economies. Quality issues are a major barrier to market access wherever markets are 'quality conscious'. In Africa, urban markets are becoming increasingly quality conscious and regional and international markets both work to well-defined quality grades and standards. The estimation of grain quality in relation to the prevailing grades is the easiest way to assess quality changes but the quality of grain may be affected in ways that are not necessarily assessed by normal grading systems, for example changes that impact on the nutritional quality of grain. This may for example be due to ageing of the cereal grain or selective feeding on it by pests, and health hazards if there is mould growth resulting in contamination with mycotoxins such as aflatoxin (FAO, 1983; World Bank, 2011).

Losses of quality in cereal grain are potentially very important and to those farmers who make their livelihoods from grain there is evidence that they can be even more important than losses of quantity (Adams and Harman, 1977; Compton *et al.,* 1989; Compton, 2002). Losses of quality must be taken into account when implementing loss reduction programmes as 1) both qualitative and quantitative losses have a bearing on the cost/benefit of any loss reduction interventions, and 2) quality losses need to be identified, targeted and then monitored to demonstrate the efficacy of loss reduction interventions. Furthermore, in developing countries most losses of quantity or quality occur, or are at least initiated, at farm level (Hodges *et al.,* 2010). This leads to a need for expensive and wasteful conditioning of the crop later in the value chain to bring it to the standard required for market. Thus the efficiency of the value chain, on which the livelihoods of producers depends, can be substantially improved if producers can be encouraged to preserve grain quality.

But producers will not deliver better quality grain unless there is an incentive to do this. In particular, better quality needs to receive a price premium that rewards their efforts. This is especially important when producers have competing priorities. This often happens just after harvest when farmers have the choice of devoting time to good postharvest handling and storage, which is essential for retaining grain quality, or of devoting time and effort for planting the next crop. The value of the next crop is usually much greater than the value loss in quality of the recent harvest, so farmers will prioritise activities that give them best benefit. But priorities can change dramatically if there is a price incentive and if farmers have access to technology that enables them to meet their objectives. A good example is the use of motorised maize shellers. In Eastern Uganda, some farmers' organisations have access to such shellers, which reduce the amount of time and effort required to process maize. This maize is of better quality with fewer stones and less broken grain than that produced by manual shelling and as this postharvest handling is quicker it leaves more time to devote to planting the next crop. The warehouses receiving this maize have noted a significant improvement in quality for which a premium is paid. This more than covers the costs of using a motorised sheller.

2. Weight loss versus quality loss

Weight loss is the standard international measure of grain loss because it is useful in quantifying the national impact of losses and for comparing losses across sites and years (De Lima 1979). Furthermore, losses in weight are more easily measured than quality losses. Weight losses are determined by collecting and weighing the grain excluded from the system, e.g. grain that is not collected at harvest, is scattered during threshing etc., and by determining what weight of grain remains after a postharvest activity e.g. after farm storage. Weight losses are normally expressed in terms of dry matter, i.e. this does not include any changes in weight that might occur due to changes in moisture content. Quality change is difficult to determine as it is not necessarily expressed as a single factor but by the many factors included in an official grading standard. But the change in quality is not necessarily a loss until it has resulted in a financial/economic loss and it is at this point that the situation becomes complex. The relationship between the quality of grain and grain value is not simple and varies from market to market and over the course of a season. For example, when grain is scarce, such as in the period just before a new harvest, there is little good quality grain on the market so that poor quality grain may sell for a price that is greater than that received for better quality grain just after harvest when grain is plentiful. Even if the relationship between quality and value is well understood (or given a nominal value) there are further problems

1) Data on grain quality, particularly at farm level are scarce. Part of the reason for this is that official grading of grain does not take place until it is in the formal market. But grain is often conditioned before it reaches the formal market and the quality loss goes unrecorded.
2) Informal markets are often insufficiently quality conscious to distinguish between grades, and
3) Across formal markets, different countries are operating different grading systems for each grain type, so there are several measures of grain quality that are not equivalent, i.e. cannot be translated from one to the other.

Only in extreme cases does APHLIS take into consideration loss of quality and when it does the loss of quality is converted into weight loss. According to APHLIS if grain is fit for human consumption then nothing has been lost, irrespective of any quality loss, for example the grain has been downgraded from grade 1 to grade 3, for which there would be a financial loss. However, if the quality for grain has declined to the extent that it is no longer fit for human consumption then it is considered to be a 100% weight loss (Fig. 1), even if this means that it is downgraded to animal feed for which the seller will still receive some, but diminished, financial reward. But grain subject to losses of quality or quantity may consequently be of lowered human nutritional value or present a health hazard, for example be contaminated with mycotoxins, which are found especially on maize grown in more humid areas (mycotoxin contamination is discussed in more detail below).

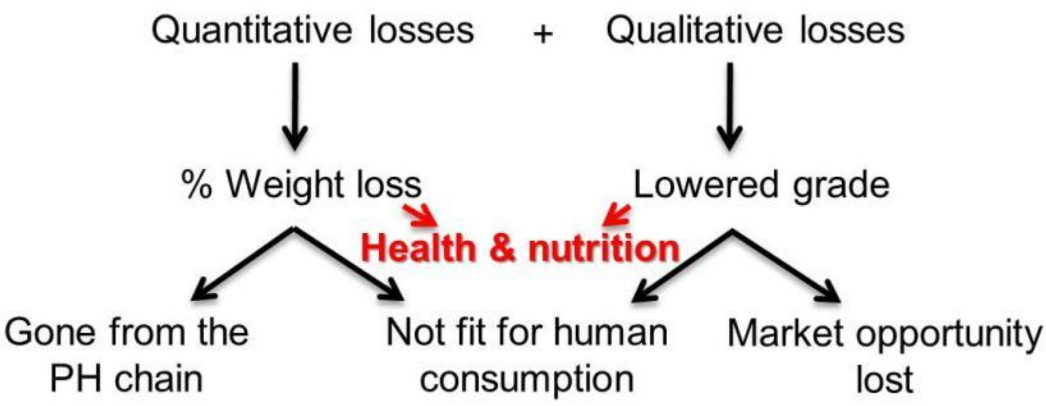


Figure 1 – The relationship between losses of quality and losses of quality.

There is very little data on the relative values of the two types of loss. A detailed modelling approach to the estimation of total loss (quantitative and qualitative) was undertaken with farm stored maize in Cameroon, but this only considered insect damage (McHugh 1994). We are only able to quote three studies that have attempted to place a value on the losses of the cereal grain sold by smallholder farmers in Africa, where weight and quality losses are taken into account. These were undertaken on the maize of smallholder farmers in Zambia (Adams and Harman, 1977) and Ghana (Compton *et al.* 1998 ; Compton 2002). In Zambia, estimates of the cash costs of losses showed that on average quality losses had twice the value of weight losses (Table 1).

Table 1: The cost of losses during maize storage at two locations in Zambia, in Zambian Kwacha (Kw1.2 = US$1) (from Adams and Harman, 1977)

		Direct			Indirect* (insecticides)
	Total direct + indirect costs	**Total direct costs**	**Weight**	**Quality**	
Chivuna	68.93	54.98	20.22	34.76	13.95
Chalimbana	26.12	21.47	3.51	17.96	4.65
Total	95.05	76.45	23.73	52.72	18.6
Mean all farmers	11.88	9.56	2.97	6.59	2.33

*Indirect losses are costs involved in the prevention of losses, in this case the application of storage insecticides

In Ghana, when weight loss was less than 5%, loss in maize value was found to be negligible; however at higher levels of weight loss, value loss was estimated to be about 3-5 times as high as weight loss. A survey of 96 farmers who disposed of the stored maize showed an average value loss of about 10% at the time of disposal, which was of much greater significance than weight loss in storage.

The question remains, how would the two types of loss be routinely combined to give a clearer picture of the significance of postharvest losses. **In order to combine losses of quantity and quality to give a single estimate of loss, it is necessary to express both types of loss in the same units.** The only units they could have in common are financial, thus both would have to be given a monetary value. At least in theory, it would not be difficult to put a maximum financial value on production, making assumptions about the rate of supply of grain to the market and the typical market price trends for top quality cereals. The value of weight losses from this system would be easy to estimate but the difficulty is that there are no substantial data on the magnitude of quality losses and, as already explained, the relationship between quality and value is complex. Although there have been some research studies in this area, under normal circumstances it is unlikely that practitioners would attempt to combine such loss data. Although in justifying and in evaluating loss reduction programmes they will need to refer to both types of loss. The implications for APHLIS are that the weight losses it quotes are only one component of losses and do not reflect the full economic loss, although for determining food availability/food security weight losses are still invaluable.

3. Why does grain quality decline

Poor postharvest handling and storage (PHHS) results in a reduction in grain quality. The starting points for grain quality decline are poor handling that allows -

Contamination with foreign matter - Foreign matter includes organic matter (e.g. chaff, other types of grain) and inorganic matters (stores, soil). Some organic matter may be classified as filth (e.g. rodent droppings and hair, bodies of dead insects etc.). Contamination with foreign matter accumulates during the early stages of postharvest handling when there is insufficient care at harvesting, drying and threshing and then the accumulation of filth may continue due to the activities of insects and rodents.

Mechanical damage during handling - Rough handling of grain results in grain breakage, this may happen at any point during postharvest handling and storage but is especially a problem during threshing. For example, many farmers thresh maize by placing maize cobs in a sack and beating them with sticks. This results in a high proportion of broken grain. The presence of broken grain by itself is a reduction in quality for all types of cereals and an important reason for this is that broken grains are much more susceptible to other types of quality decline such as attack by moulds and by insects (discussed in more detail below).

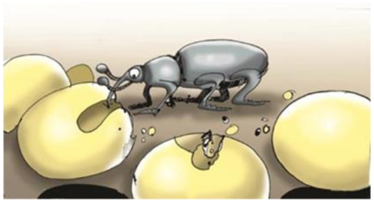
Insufficient drying - Grain that is not dried to a safe moisture content very soon after harvest will start suffering quality decline due to attack by moulds. Moulds may develop on the surface of grain that is above the safe moisture content, which under hot tropical conditions is around 14%. High moisture content is also favourable for the development of insect infestation and for grain discolouration. Taken together mould and insect attack are called biodeterioration.

Insufficient protection during storage - Poor storage arrangements can allow the entry of water, access of insects and rodents, and chemical browning reactions that lead to grain discoloration.

3.1 The low quality factors

Some of the factors by which grain quality may be judged are shown in Table 2 (taken from Hodges and Stathers, 2012). Most of these are a consequence of a process called biodeterioration.

Table 2: The factors that contribute to lowering the quality of cereal grain

<table>
<tr>
<td rowspan="6">High quality grain
</td>
<td></td>
<td>Foreign matter and filth
Grain may be contaminated with foreign matter that is either organic (e.g. maize cob cores, tassels etc) or inorganic (e.g. stones). Examples of filth are rodent dropping and dead insects. Careful sieving can reduce much of the foreign matter content.</td>
</tr>
<tr>
<td></td>
<td>Broken grain
Most broken grain comes from poor postharvest handling especially shelling/ threshing, but may also be a consequence of pest attack.</td>
</tr>
<tr>
<td></td>
<td>Insect damage
Insects make holes in grains and hollow them out.
</td>
</tr>
<tr>
<td></td>
<td>Rodent damage
Rodents chew into grain and remove the germ.
</td>
</tr>
<tr>
<td></td>
<td>Mould damage
Mouldy grains have been dried too slowly or allowed to become wet. They have patches of mould growth on them and may also be discoloured. Some moulds also produce mycotoxins that are dangerous poisons, e.g. aflatoxin, but physical appearance is no guide to aflatoxin contamination.</td>
</tr>
<tr>
<td></td>
<td>Discoloured grain
Grain may be discoloured due to grain heating.</td>
</tr>
</table>

3.2 Biodeterioration

Biodeterioration is due to the effects of pests as well as natural chemical changes within the grain. Pest problems and these natural chemical changes generally proceed more rapidly under higher temperatures and greater relative humidities; for every 10°C rise in temperature the speed of a chemical change is doubled.

Good examples of natural chemical changes that happen over time are the increases in

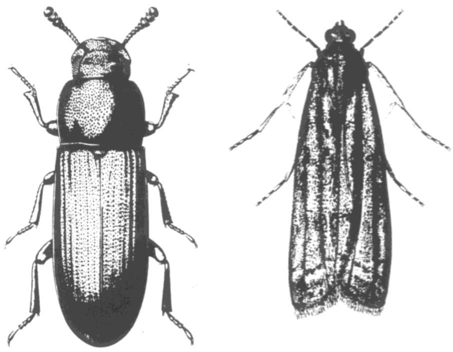
- rancidity of milled rice
- number of discoloured maize grain,
- number of yellow grains of milled rice
- number of non-viable seed grain

Besides happening more rapidly at higher temperatures and humidities, these changes can also happen more quickly due to pest attack. Good postharvest handling and storage can slow down all these quality changes.

The main organisms attacking grain during postharvest handling and storage, sometimes including birds, are generally

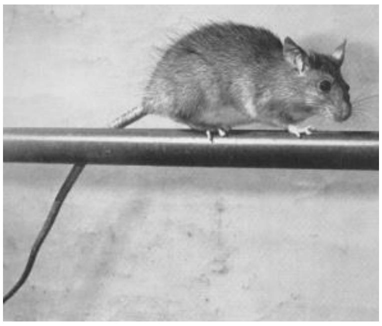
- insects (mostly beetles and moths)
- moulds, and
- rodents (mostly rats and mice)

Each of these is considered in more detail below.



Insects – beetle(left) and moth(right)

Moulds



Rodents

3.2.1 Insects

About thirty species of insects commonly infest grain. Most of the insect pests are either beetles or moths although there are some other types (not dealt with here). Insects have six legs and are usually easily visible since they are in the range of 1 to 15 mm long.

As well as attacking grain, several insect pests create other types of damage and all contribute filth to the grain through dead bodies and their dropping which include uric acid. Some species that bore into grain may also burrow into wooden or plastic structures so weakening them. The larvae of many moths produce large quantities of silken threads when moving over surfaces. This builds up into a webbing that can bind flour and grain together into a solid mass so blocking machinery or causing additional machine wear and breakdowns.

Insects that attack cereals are usually divided into two groups: primary pests and secondary pests. It is useful to distinguish between them as primary pests are usually more destructive than secondary pests, especially in short-term storage.

Primary insect pests are insects that can attack and breed in previously undamaged cereal grains. Such pests can also feed on other solid but non-granular commodities, but they are rarely successful on milled or ground foodstuffs. Examples of primary pests include the beetles *Sitophilus* spp (Fig. 1), *Rhyzopertha dominica* and *Prostephanus truncatus* (Fig. 2) and the moth *Sitotroga cerealella*. Many primary pests attack the commodity in the field prior to harvest. Some species spend their pre-adult life concealed within a grain, making them difficult to detect visually.

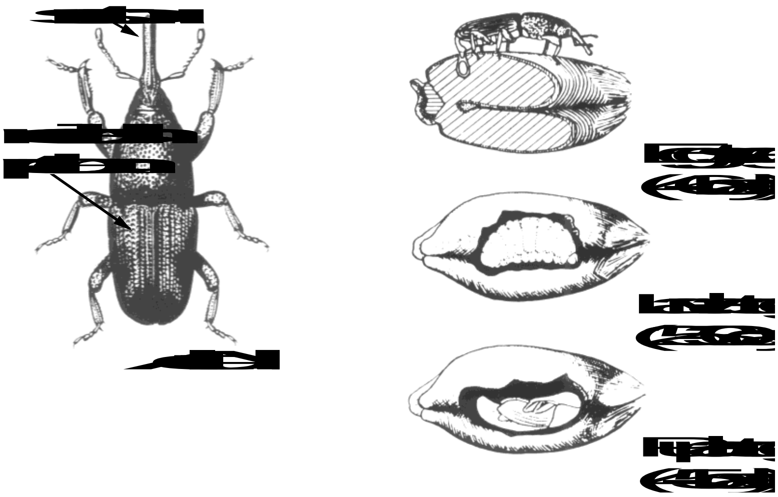


Figure 1: *Sitophilus zeamais* (adult life size 2.5-4.5 mm) showing its lifecycle in a wheat grain. Note at top right, a female weevil laying an egg in a hole it has made in the grain

Figure 2: *Rhyzopertha dominica* (left - life size 2-3 mm) and *Prostephanus truncatus* (right - life size 3-4.5 mm)

Secondary insect pests are not capable of successfully attacking undamaged grains. They are, however, able to attack materials that have been previously damaged either by other pests (especially primary pests) or by poor threshing, drying and handling. They are also able to attack processed commodities such as flour and milled rice where they may form the majority of insects present. Secondary pest species appear to attack a much wider range of commodities than primary pests. Feeding stages of these pests live freely, i.e. not concealed within individual grains. Examples of widespread secondary pests are the beetles such as *Tribolium castaneum* (Fig. 3) and moths like *Ephestia cautella* (Fig. 4).

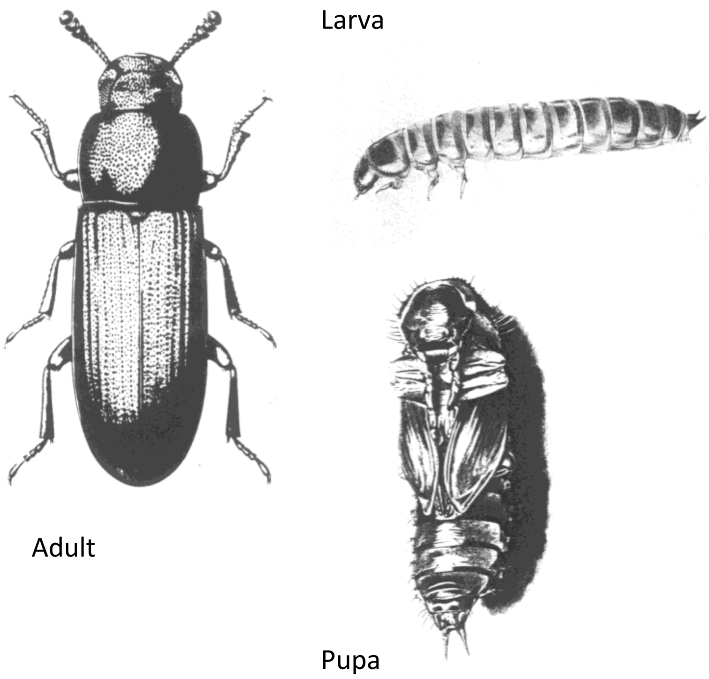


Figure 3:*Tribolium castaneum*, adult (life size 2.5-4.5 mm), larva and pupa

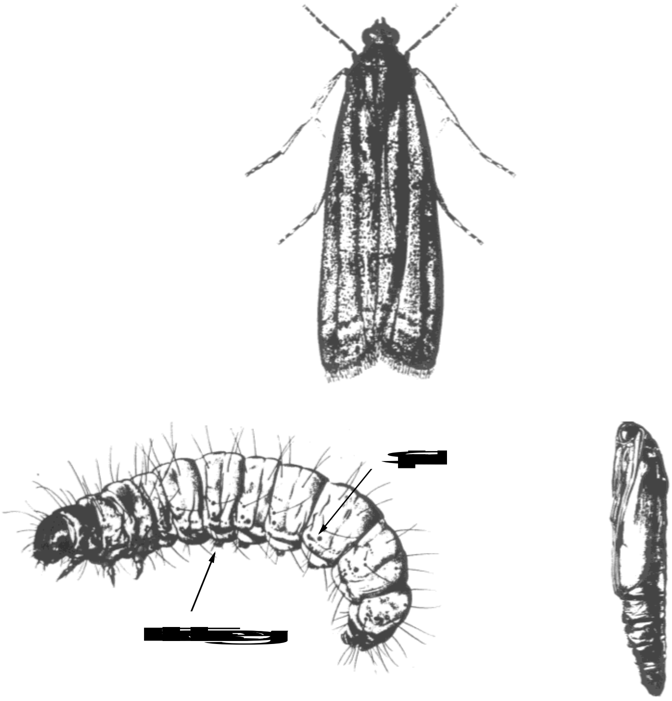


Figure 4: *Cadra cautella,* adult (wing span 11-28 mm), larva and pupa

More detail of a full range of storage pests is presented in Annex 1.

3.2.2 Rodents

Rodent problems may vary from just the occasional damaged grain sack to severe damage that results in the collapse of bag stacks.

Grain may be eaten in the field or in store by rodents. Apart from the food eaten, spoiled or contaminated, there are additional ‘invisible’ losses such as the replacement or repair of packaging materials and the cost of rebagging spilled food. Much of the spillage arises when rodents attack food packaging to obtain nesting material; stacks of heavily infested bagged foodstuffs may ultimately collapse. Rats and mice gnaw inedible materials including electrical wiring, so their presence in buildings can constitute a fire hazard. Finally, rodents are capable of transmitting diseases to people either directly by bites, through the air or the handling of rodent carcasses; or indirectly through contact with food and water contaminated with rodent hair, droppings and urine, which also constitute filth in the grain.

3.2.3 Moulds

The moulds, also called fungi, that are found on stored grain initially grow on the surfaces of grain and then slowly penetrate and destroy them (Fig. 5). These moulds have tube like filaments called hyphae that form the main part of their body. They reproduce by forming spores that are usually released in enormous numbers. Although many types of mould are very important as agents of natural decay, they also cause decay where it is not wanted such as on cereal grains.

Figure 5: Mould damaged maize cob

Mould growth on grain is only possible when the relative humidity at the grain surface layer is at more than 70%. The humidity at the grain surface layer is determined by the grain moisture content and for most cereals the corresponding moisture content in equilibrium with 70% relative humidity is about 14%. Keeping grain at or below this safe storage moisture content is essential if mould growth is to be avoided. Physiologically mature grain may become mould infected because when physiologically mature the plant's own defences against mould attack are lowered. However, the growing crop in the field can also become infected if subject to drought stress as this also reduces the plants defences against mould growth. Mould may also grow on moist grain that has been left exposed by the attack of field pests.

Mould growth can cause heating and caking of the grain, and subsequent discoloration due to either production of pigments or browning reactions occurring at the elevated temperatures. Caking and heat damage of grain are typical signs that mould growth has already occurred. Besides causing this type of damage, moulds may also produce toxic chemicals called mycotoxins. The range and status of mycotoxins in African produce has been reviewed recently by Wagacha and Muthomi (2008).

Mycotoxins are mould metabolites that, when ingested, inhaled or absorbed through the skin, cause lowered performance, sickness or death in man or animals. The amount formed depends on several factors, including temperature, moisture content, and type of grain. The resultant diseases in man and other animals are not contagious or infectious, and cannot be treated with drugs or antibiotics. Their effects depend on the animal species and the toxin concerned. Some animals appear to be more susceptible than others, and different mycotoxins affect different organs of the body, including liver, kidneys, skin and the nervous system. Mycotoxins may move in the food chain so that the possible concentration of mycotoxins in animal products, especially milk, could be a further source of danger to consumers.

There are many different mycotoxins that could contaminate grain. The most well known is aflatoxin. This is produced by some strains of the mould *Aspergillus flavus* and is regarded as the most important mycotoxin in developing countries. It is a liver toxin which can induce cancer in susceptible animals, and is the most potent liver carcinogen known. Much circumstantial evidence suggests that it may be a factor in the high incidence of human liver cancer in some parts of the tropics and subtropics. Subsistence farmers in drought seasons, or situations of food insecurity, often have no choice but to eat mouldy maize and groundnuts. More than 125 people were reported to have died due to acute aflatoxicosis in Kenya when food insecurity, caused by a variety of climatic and social reasons, led to widespread consumption of maize contaminated with high levels of aflatoxins (Lewis *et al*., 2005). However, the chronic affects of aflatoxin ingestion may be a much greater issue since the poison accumulates in the liver, and frequently causes liver cancer after long exposure. The combination of aflatoxin ingestion and HIV/AIDS infection or malaria means that many may be dying or leading unproductive lives as a result of aflatoxin, but die from being rendered more susceptible to other diseases.

The growth of *A. flavus* can be very rapid under tropical or subtropical conditions, and aflatoxin has been found in a wide variety of foodstuffs including cereals, pulses, and oilseeds (especially groundnuts). There are a number of aflatoxins produced by *A. flavus* the most important of which is aflatoxin B1. The degree of aflatoxin contamination can be made part of a grain standard, which is the case with the East African maize standard (Table 3). Here the total allowable contamination with aflatoxin is 10 ppm (1 part per million = 1mg in 1kg of grain). Of this 10ppm aflatoxin allowance, aflatoxin B1 should not contribute more than 5 ppm. Relatively simple test kits are now available for warning of the presence of aflatoxin on grain but accurate measurement and separate estimation of aflatoxin B1 requires careful testing with sophisticated equipment.

For growth *A. flavus* requires a minimum relative humidity of 82%. For cereals at typical tropical temperatures (20°-30°C) this would be equivalent to a moisture content of about 18%. It is therefore, clear that if cereal grain is maintained at about 14% it is safe from aflatoxin formation. However, during postharvest handling if moist grain is not dried quickly and thoroughly it is in danger of *A. flavus* infection and toxin formation. For this to happen the grain must be contaminated with the spores of *A. flavus* and the likelihood of this is greatly increased if the grain is allowed to come into contact with soil or other mouldy grain during postharvest handling. Good hygiene is thus important in avoiding contamination (Golob, 2007). However, it should be remembered that grain may become contaminated while on the plant in the field due to drought stress.

If mould damage and toxin formation has been avoided during postharvest handling and the stored grain remains at the safe moisture content then it should remain free of aflatoxin. The main danger is water coming into contact with the grain, due to leakage or condensation. In large scale storage there is also a danger of hot spots occurring in the grain due to insect infestation, this results in high temperature and moisture which presents a danger, but these conditions have not been reported from small bulks of grain stored by smallholders or in sack storage.

Grain may become damaged by mould under the following conditions -

- During postharvest handling when the grain has not been dried below the safe moisture content quickly, especially if it has come into contact with soil or old grain, which contain mould spores. **To avoid this problem dry grain promptly and away from contact with soil or residues of grain from previous harvests.**
- During storage when grain has become damp due to water leakage/condensation or in the case of a large grain bulk the formation of hot spots due to insect activity. **To**

avoid these problems make sure that stores do not leak water or suffer condensation and in large grain bulks ensure timely pest control operations.

- When the growing crop is subject to drought stress or moist grain left exposed by the attack of field pests. **To avoid this problem, carefully select and remove damaged grain during postharvest handling.**

4. How formal markets measure quality loss

For any one type of grain (maize, wheat, sorghum etc.) traded in a formal market, there may be several different quality grades. Cereals are bought and sold according to specific quality grades; these are usually determined by national or regional authorities. When seeking to purchase grain, a buyer will usually specify a particular quality grade in order to meet a particular end-use. For example, this could be for international export or food aid where high quality grain is required, for local consumption where reasonable but not such high quality is demanded, or for animal feed that requires only relatively low quality. In many cases, grades are specific to a national or regional marketing system. For example there are five different grades of maize specified by the US Department of Agriculture whereas there are only three grades in South Africa. When talking about commodity quality grades, people also refer to 'commodity standards'. A standard is a set of one or more quality grades and these are usually enforced by law.

The grade of a sample of grain is determined by careful analysis in a grain laboratory, according to a carefully defined method. The methods employed differ as each standard is different and the acceptable limits for each quality factor differ between grades and between the standards. A good example of a commodity standard is the one for maize in East Africa; this has two grades (Table 3).

Table 3 – East African maize standard

Quality variable		Maximum limits	
		Grade 1	Grade 2
Moisture content %		13.5	13.5
Foreign matter total %		0.5	1.0
of which	Inorganic matter %	0.25	0.5
	Filth %	0.1	0.1
Broken grain %		2.0	4.0
Defective grain, total %		4.0	5.0
of which	Pest damaged grain %	1.0	3.0
	Rotten and diseased grain %	2.0	4.0
	Discoloured grain %	0.5	1.0
	Immature/shivelled grain %	1.0	2.0
Other grain %		0.5	1.0
Aflatoxin contamination (total)		10 ppb	10 ppb
of which	aflatoxin B1	5 ppb	5 ppb

You can see that each grade has a certain maximum limit for each of a number of quality variables (features).

- Moisture content- for either grade the amount of moisture in grain must not exceed 13.5%

- Foreign matter - the grades differ in how much inorganic matter (stones etc) is acceptable but are the same with respect to filth (rodent dropping, dead insects etc).

- Broken grain – Grade 1 may only have half as much broken grain as Grade 2.

- Defective grain - in Grade 1 not more than 4% of grain can be 'defective' while in Grade 2 not more than 5%. Defective grain is the sum of four different types of damaged grain - pest damaged, rotten and diseased, discoloured, and immature/shrivelled). Notice that each different damage type has its own maximum limit. In the case of Grade 1 maize, if the maximum allowable limit for each damage type was added together it would be 4.5%. This would exceed the grade maximum which is only 4%. So to remain within the grade limit not all grain defects can be at the maximum.

- Other grain – the presence of other cereals or pulses (sorghum, wheat, millet, beans etc), Grade 1 may have only half as many as Grade 2.

- Aflatoxin – this is a mixture of toxic products mostly from *Aspergillus flavus* but also certain other moulds that may infect maize and other grains. There is no difference between the grades in the maximum limit.

Besides grades and standards, there are also commodity segregations. For example maize may be of the flint type or dent type. There may be commercial uses of flint or dent which require them to be separated in trade. However, they are both subject to the same grading system, so in a store Grade 1 flint and dent grain may be segregated so that buyers can purchase what they want. But if flint and dent maize were mixed this would not affect their grade.

Quality loss on the basis of a change in formal grade has been measured for the maize grain held in farm storage in Zambia (Adams and Harman, 1977). The authors concluded that figures derived in this way were considered to have limited usefulness and should be viewed as a basis on which to compare losses in maize occurring during storage by smallholder farmers with those that may take place elsewhere in the postharvest chain, i.e. are likely to have more comparative than absolute value.

5. How informal markets measure and value quality

In informal markets, where grades and standards do not operate, establishing the value of losses is complex. There have been few studies of this subject and of these most have assumed that loss in value is equal to the weight of grain lost multiplied by the price of undamaged grain. However, when looking in more detail this appears not always to be the case, especially as in informal markets grain is often sold by volume and not by weight. In cases where weight losses reached up to about 5% due to insect damage, loss in maize value may be negligible because the volume of the grain is effectively the same as that of undamaged maize and the price is unaffected by low levels of damage, especially when slightly damaged grain can be mixed with good grain to obtain 'top quality' maize (Compton, 2002).

Only rarely has the value of quality losses been examined in informal markets, where specific grades are not enforced so in theory there would be a continuous relationship between price and quality (if there are grades enforced then there are price steps i.e. price and quality do not have a continuous relationship). One published example is how insect damage affected the price of maize in an informal market in Ghana (Compton *et al*. 1998). In this study, panels of experienced maize traders suggested prices for pre-prepared maize samples showing different degrees of insect damage. The relative price of damaged maize was quite consistent across the markets studied. At harvest a 1% increase in damaged grains decreased price on average by 1%, but later more damage was tolerated as maize became more scarce (Table 4).

Table 4. The relationship between market availability and the effect of insect damage on market price (from Compton *et al.,* 1998)

Availability of maize on the market	Maize given top price (% damaged grains)	Price of highly damaged maize (>90% damaged)
Plentiful (soon after harvest)	0-5%	Unlikely to sell
Moderate (mid-season)	0-5%	Unlikely to sell
Scarce (lean season)	0-7%	25%
Very scarce (bad years)	0-10%	30%

Factors other than just insect damage are important in establishing the quality/value relationship of maize in Ghana (Compton, 2002). At very low levels of insect damage these other grain characteristics were more important in the determination of price. However, at levels of 10% damaged grain, the effect of insect damage outweighs all other factors, except mould. These other factors include

Variety – small grained local varieties were preferred, with HYVs discounted by 10-15%.

Moisture content – Traders judged grain MC by feel, bite and sound. The major harvest is in the rainy season and very wet maize (26% MC) is heavily discounted (10-40%) at that time although maize even at 19% MC was not discounted.

Percieved age – The response to age varied, some areas preferring maize from the previous harvest, and other from the new harvest. Those preferring old maize discounted new maize by up to 10%. Those preferring new maize generally gave new and old, undamaged, maize the same price.

Colour – Yellow and purple grains are common in local varieties, but are disliked by consumers who say they discolour the flour. A sample containing 6% purple grains was discounted by 25%, although most traders did not discount.

Mould – Mouldy grain is rarely bought or sold. At low levels (less than 5% of grains discoloured by mould) mould is equivalent to insect damage in its effect on price. At higher levels, mouldy grain very rapidly declines in price, so that when discoloured grains reach levels higher than about 30% the grain has little or no remaining value.

The next section deals with the approaches that can be taken by farmers to reduce losses of quality and quantity. When it comes to loss reduction activities there is no distinction between the two types of loss.

6. How to tackle losses of quality and quantity

As losses of quality and quantity of cereal grains in developing countries appear to be initiated mostly at farm level, the potential remedies to the problem need to be applied at the same level. However, as emphasised before, there has to be an incentive before smallholder farmers will adopt improved postharvest practices and they also require access to technical know-how and equipment appropriate to their circumstances. From time to time farmers may have been encouraged to produce crops that are not suitable for the prevailing conditions. A good example of this concerns maize. In many places in Africa maize was originally cultivated as a vegetable crop (i.e. picked when green and the grain consumed when moist). More recently, there has been a drive to dry and store maize grain as a means of household/national food security. This can work well if the grain can be dried to a moisture content that is safe for storage. However, if the harvest falls at a time of wet cloudy weather then the grain will be difficult to dry and so quality is lost (and there is danger of mycotoxin formation). In theory, the solution is artificial drying but in most circumstances this is not economically feasible. It would therefore be better for farmers to remain producers of green maize and use other crops to raise cash and other strategies to ensure food security.

As an aid to those involved in helping smallholder farmers limit grain losses (of both quantity and quality), recommended approaches to the following postharvest activities can be accessed through the web pages of APHLIS:

- Prepare for the new harvest

- Harvest on time
- Harvest carefully
- Dry the crop sufficiently
- Thresh/shell the crop carefully
- Clean the grain
- Store the grain using an appropriate method
- Using insecticides and other ways of killing insect pests in stored grain

These recommended approaches are adapted from the UN World Food Programme's 'Training Manual for Improving Grain Postharvest Handling and Storage' (Hodges and Stathers 2012).

7. Conclusions

It is important to understand quality losses, and take them into account, as they probably have a more significant economic impact than weight losses. However, quality loss estimation is difficult because ultimately what is of concern is the loss of market opportunity/ income. Although reduction in quality can be measured, i.e. a reduction from grade 1 to grade 2 determined by the parameters of a grading system, the relationship between quality and value is complex. This may be because markets are insufficiently quality conscious to distinguish between grades, or grade 1 soon after harvest may actually sell for less that grade 2 six months after harvest when grain is scarce. Consequently, in the past most loss estimation has focused on weight loss. Nevertheless, quality loss is an important consideration because it is a direct loss of value; it may also impact on food safety and nutrition. It is likely to be very convenient as a means to monitor loss reduction strategies, although if food security is a primary concern then weight loss will remain a key measure.

The implications of this review for APHLIS are that the weight losses it quotes are not necessarily the major component of economic losses and that engagement with quality loss is essential in any endeavour to help promote postharvest loss reduction. Put simply, if farmers do not receive better incomes from better quality grain then the resources they will devote to postharvest handling and storage will be insufficient to make a reduction in postharvest losses. Quality loss of cereal grains in developing countries appears to be initiated mostly at farm-level, so the potential remedies for the problem are needed at the same level. Consequently, APHLIS is offering a series of web pages that document practical approaches that smallholder farmers can take to reduce losses.

The area of quality losses still remains relatively under-researched. There are clearly opportunities to use conventional grading systems to report on the postharvest performance of the smallholder; especially simple visual-scales that relate directly to these grades. APHLIS is in the process of developing a standardised approach to the collection of the loss data that are needed to make postharvest weight loss estimates, but it will include suggestions for quality loss assessment. However, a particular challenge remains; how to put a monetary value on both quality and weight losses so that they can be combined into a single loss figure – the postharvest value losses.

Now for more information about preventing postharvest losses of quality and quantity on-farm, check the APHLIS website where you can find web pages devoted to the relevant links in the postharvest chain and a downloadable PDF containing the same information.

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Annex 1 - Insect pests of cereal grains

About thirty species of insects commonly infest grain. Most of the insect pests are either beetles or moths although there are some other types (not dealt with here). Insects have six legs and are usually easily visible since they are in the range of 1 to 15 mm long.

As well as attacking grain, several insect pests create other types of damage. Some species that bore into grain may also burrow into wooden or plastic structures so weakening them. The larvae of many moths produce large quantities of silken threads when moving over surfaces. This builds up into a webbing that can bind flour and grain together into a solid mass so blocking machinery or causing additional machine wear and breakdowns.

Life stages of insects and mites in stored food

During the course of their lives, insects pass through a number of stages. The adult stage is responsible for reproduction. After mating, females lay eggs in selected places. Immature insects hatch from the eggs and then feed and grow to become adults. For many insects, the immature stage differs in form greatly from the adult and is called a larva (Fig. 1.1). When the larva hatches from an egg it is very small, typically 1-2 mm long. It begins to feed and grow immediately but the larval skin is unable to stretch so the larva must shed its outer skin, a process called moulting, to allow growth. Moulting occurs several times and when a larva is fully grown, the final moult produces an immobile stage, known as a pupa (Fig. 1.1). Although the pupa is unable to move about, it is physiologically very active with the tissues becoming re-organised so that the larva changes (or metamorphoses) into the adult. At the end of the pupation period (typically 5-6 days), the fully formed adult emerges from the pupal skin (Fig. 1.1).

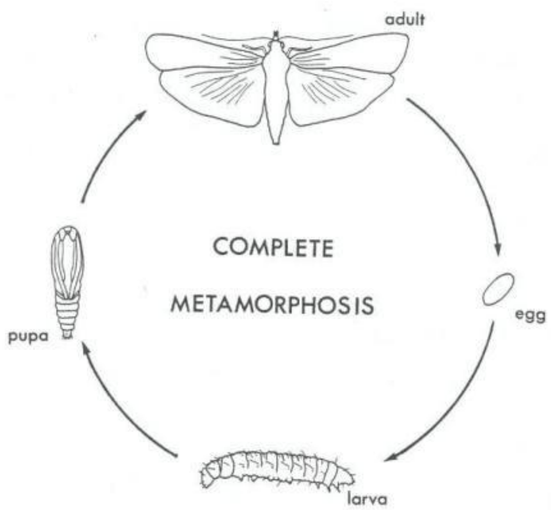

Figure 1.1 Insect lifecycle

Insects that attack cereals are usually divided into two groups: primary pests and secondary pests. It is useful to distinguish between them as primary pests are usually more destructive than secondary pests, especially in short-term storage.

Primary insect pests are insects that can attack and breed in previously undamaged cereal grains. Such pests can also feed on other solid but non-granular commodities, but they are rarely successful on milled or ground foodstuffs. Examples of primary storage insect pests include the beetles *Sitophilus* spp and *Rhyzopertha dominica* and the moth *Sitotroga cerealella*. Many primary pests attack the commodity in the field prior to harvest. Some species spend their pre-adult life concealed within a grain, making them difficult to detect by visual inspection.

Secondary insect pests are not capable of successfully attacking undamaged grains. They are, however, able to attack materials that have been previously damaged either by other pests (especially primary pests) or by poor threshing, drying and handling. They are also able to attack processed commodities such as flour and milled rice where they may form the majority of insects present. Secondary pest species appear to attack a much wider range of commodities than primary pests. Feeding stages of these pests live freely, i.e. not concealed within individual grains. Examples of widespread secondary pests are the beetles such as *Tribolium castaneum* and moths like *Ephestia cautella.*

Some pests do not fall easily into either category: for example the beetle *Trogoderma granarium* is only just capable of attacking undamaged commodities but develops much more rapidly if some previous damage is present. In such cases, it is best to classify these species as secondary pests, partly because they do not develop successfully on undamaged grains but also because they usually exhibit other secondary pest characteristics, e.g. a wide range of food preference.

Primary pests of cereals

***Sitophilus* spp.**	**1^{ary} beetle pests of cereals**

Beetles of the genus *Sitophilus* are important primary pests of whole cereal grains and are called 'weevils'. Three species are pests of stored grain, *Sitophilus zeamais* (maize weevil), *Sitophilus oryzae* (rice weevil) and *Sitophilus granarius* (granary weevil). The common names are misleading and should not be used in scientific communications. The adults of all three species are small, insects with a narrow snout that carries the mouthparts. The body colour ranges from light to dark brown. Both *S. zeamais* and *S. oryzae* often have four reddish-orange spots on their wing cases (Fig. 1.2).

Sitophilus larvae are whitish, legless grubs that spend all of their pre-adult life tunneling in a cereal grain. The adult female weevils lay eggs singly in tiny holes that they gnaw into a grain. Each egg is protected by a waxy 'egg-plug' that is secreted by the egg-laying female (Fig. 5.6). Upon hatching from the egg, the larva begins to feed producing a cavity in the grain as it increases in size. Eventually the fully-grown larva pupates within the grain, and the adult that emerges bites its way out of the grain leaving a characteristic large, somewhat irregular, emergence hole.

Sitophilus granarius is essentially a temperate pest and is not found in tropical countries except occasionally in cooler, upland areas. *S. zeamais* and *S. oryzae* are commonly found throughout the world in tropical and sub-tropical regions especially where ambient humidities are fairly high. Under favourable conditions, such as 27°C and 70% rh, development from egg to adult in all three species is completed in about 35 days. In *S. zeamais* and *S. oryzae* development periods are very protracted at temperatures below 18°C, whereas *S. granarius* can develop, albeit slowly, at 15°C so that the life cycle is complete in about 140 days.

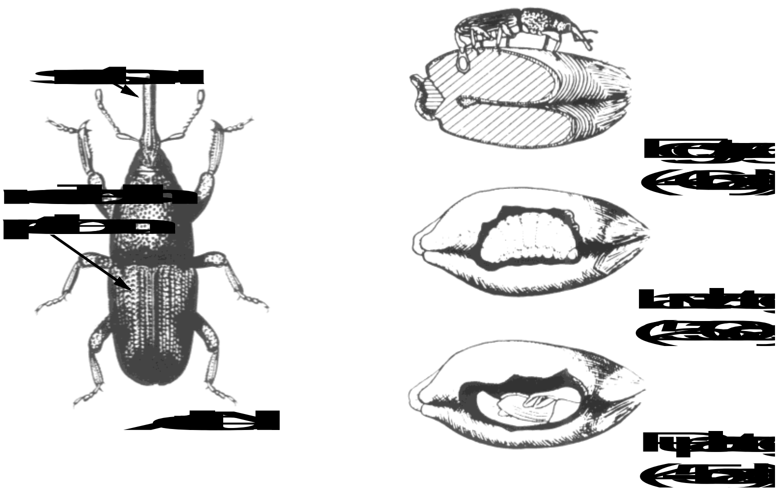

Figure 1.2: *Sitophilus zeamais* (adult life size 2.5-4.5 mm) showing its lifecycle in a wheat grain. Note at top right, a female weevil laying an egg in a hole it has made in the grain

Rhyzopertha dominica* and *Prostephanus truncatus	**1^{ary} Pests of Cereals**

Rhyzopertha dominica (lesser *grain borer)* and *Prostephanus truncatus* (larger grain borer, LGB) are able to thrive in certain cereals grains and dried cassava roots. They are important primary pests.

Adult *R. dominica* are small (about 2-3 mm) and *P. truncatus* somewhat larger (about 3-4.5 mm), both are cylindrical brown beetles (Fig. 1.3). In both species, the head is held beneath the body so that it is obscured when the insects are viewed from above (Fig. 1.3).

Figure 1.3: *Rhyzopertha dominica* (left - life size 2-3 mm) and *Prostephanus truncatus* (right - life size 3-4.5 mm)

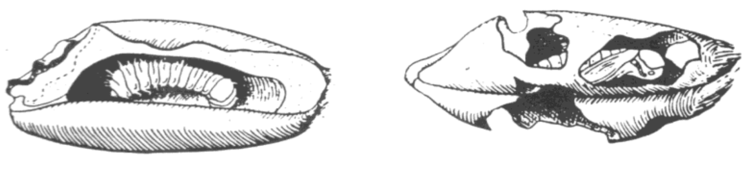

Figure 1.4: Larva and pupa of *Rhyzopertha dominica* in grain

Rhyzopertha dominica is widespread throughout the tropics and sub-tropics and is most important as a pest of wheat and paddy rice although it does occur on other cereals and roots such as dried cassava. *P. truncatus* is a sporadic but locally serious pest of maize stored on the cob in Central America. In the late 1970s, it became established in western Tanzania, where it became an extremely serious pest of farm-stored maize and dried cassava, roughly doubling average farm store losses from 5% to 10%. In individual cases, farmers might lose as much as 30%. Subsequently, it has spread to many countries in both East and West Africa. It is a serious pest in a wide range of environments but is particularly favoured by hot drier habitats.

Like *Sitophilus* spp the pre-adult stages of *R. dominica* and *P. truncatus* develop within cereal grains (Fig. 1.4). Adult females lay eggs at the end of tunnels excavated in the grain. Subsequent development usually takes place within the grain, but unlike *Sitophilus*, larvae may bore out of one grain and into another. After pupation the newly-developed adult escapes from the grain by chewing its way out then continues to bore through the food.

Adult *R. dominica* and *P. truncatus* feed throughout their lives, producing large quantities of dust and frass containing a high proportion of undigested fragments which can support the development of larvae. Both species are adapted to rather higher temperatures and lower moisture contents than *Sitophilus* spp. and they are therefore the dominant pest in hot, drier areas. Sorghum is often grown in such areas, so *R. dominica* is frequently associated with this crop. *P. truncatus* is found almost exclusively on maize and dried cassava chips. It has large populations associated with woodland habitats and individuals that have developed in wood may disperse and infest grain stores.

Sitotroga cerealella	**1ary moth pest of cereals**

Sitotroga cerealella is an important primary pest of cereals and can infest grain in the field before harvest, especially maize and sorghum. In *S. cerealella*, the fore-wings of newly-emerged adults are covered with yellowish-golden scales, but in older adults the body is entirely grey. The hind-wings carry a fringe of very long hairs (Fig. 1.5).

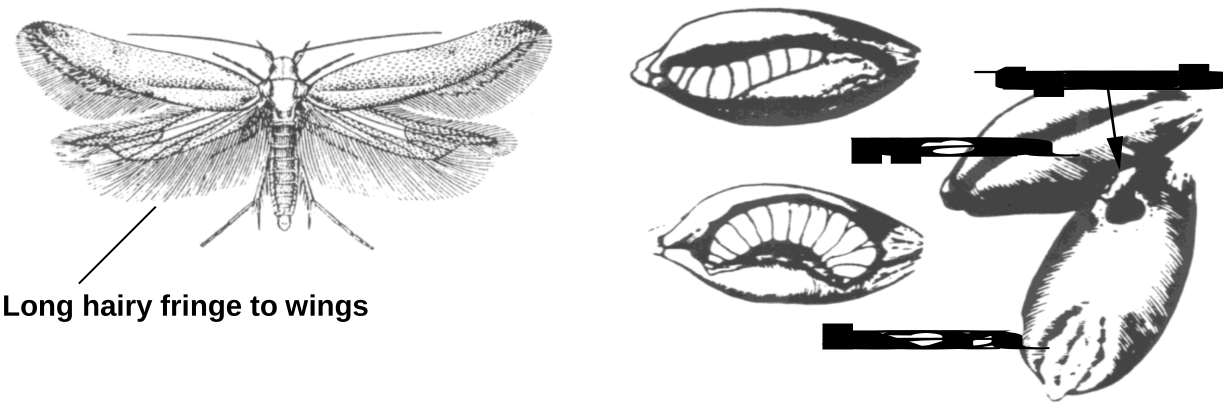

Figure 1.5: *Sitotroga cerealella* adult (wing span 10-18 mm), pupa, larva and grain with emergence window

Female *S. cerealella*, lays eggs in masses on the commodity, and, upon hatching, the larvae bore into the grain. Subsequent development takes place within the grain, but the larvae may leave one grain and enter another, especially if the grains are small. Pupation takes place within the grain, or sometimes just outside. If pupation takes place inside the grain, then before pupation the larva prepares its emergence point by chewing its way to just beneath the surface of the grain. It leaves only a thin area of grain coat, known as a window, separating the feeding chamber from the exterior. After pupation, the relatively feeble adult is able to push its way out through the window leaving a characteristic hole behind. A partial covering remains at the edge of the hole in the form of a 'trap-door' (Fig. 1.5). The adult is rather short-lived (typically 7-14 days) and is an active flyer.

Sitotroga cerealella attacks any cereal with grains large enough to support larval development. This moth is widespread over tropical and sub-tropical parts of the world, sometimes entering warmer temperate areas. The adults are good fliers and cross infestation occurs easily. They are delicate and can not penetrate far into densely packed grain; as the larvae also stay within the first seed they penetrate, infestations in bulk grain are generally confined to the outer most exposed layers. However, quite serious infestations can develop in cereals stored in bag stacks, especially if the pre-harvest infestation has been heavy. Infestations of the pest are most frequently encountered in farm storage. Because the larvae compete with those of *Sitophilus* spp., *S. cerealella* is relatively more important in dry conditions that are less favourable to *Sitophilus* spp.

Secondary pests

A large number of unrelated pests can be conveniently classified as secondary pests. They are predominantly associated with commodities that have suffered previous physical damage caused by a primary infestation or a milling process. Many are pests of cereal products, but others are associated with oil seeds, spices and other commodities.

Trogoderma granarium	**2^{ary} beetle pests of cereals and pulses**

Trogoderma granarium is a very serious pest of cereal grains and oil seeds and in many countries is listed as a ‘quarantine’ pest. Massive populations may develop and grain stocks can be almost completely destroyed. Attack occurs in large-scale stores; it appears not to have been reported from farm stores.

Adult *T. granarium* are small (2-3 mm) oval beetles (Fig. 1.6). The females are larger than the males. The wing cases are lightly clothed with fine hairs and are mid-brown in colour or irregularly mottled. Although the adults have wings they are not known to fly and appear to rely on transport in old bags etc. to get from one store to another. The larvae are extremely hairy (Fig. 5.11) and their cast skins may cover the surface of infested grain. Hairs from the skins are allergenic, presenting a health hazard to storage workers and consumers.

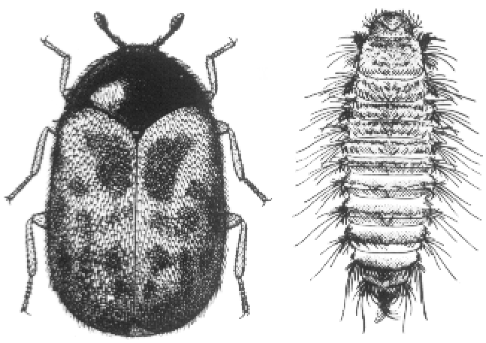

Figure 1.6: *Trogoderma granarium*, adult (life size 2.0-3.0 mm) and larva

Trogoderma granarium is very tolerant of high temperatures (up to 40°C) and low humidities (down to 2% rh). It is therefore a pest in hot, dry regions where other storage pests cannot survive. In addition, the larvae are able to enter diapause (a resting stage) when physical conditions are unfavourable. When in diapause the larvae move very little, or not at all, and their metabolic rate is lowered. In this state they can survive several years of adverse conditions. In diapause, larvae usually hide in cracks or crevices in the store, and are thus protected against contact insecticides. Their low metabolic activity also helps to reduce the rate of pesticide uptake and translocation. They are therefore very difficult to kill with residual insecticides or fumigants; although out of diapause they would otherwise be susceptible to the usual storage insecticides and fumigants.

Trogoderma granarium is widespread in the Indian sub-continent and adjacent areas and in many hot dry regions around the world. It is usually not found in humid regions.

Tribolium castaneum	**2ary beetle pests of cereals and pulses**

Tribolium castaneum feeds on a range of commodities, especially cereals, but also groundnuts, nuts, spices, coffee, cocoa, dried fruit and occasionally pulses. They will also feed on animal tissues, including the bodies of dead insects, and will attack and eat small or immobile stages of living insects, especially eggs and pupae. Under conditions of over crowding there is considerable cannibalism.

Adult *T. castaneum* are brown, medium sized (2.5-4.5 mm), parallel-sided beetles that are partially dorso-ventrally flattened (Fig. 1.7). The larvae are cream or pale brown, have little hair and are very active.

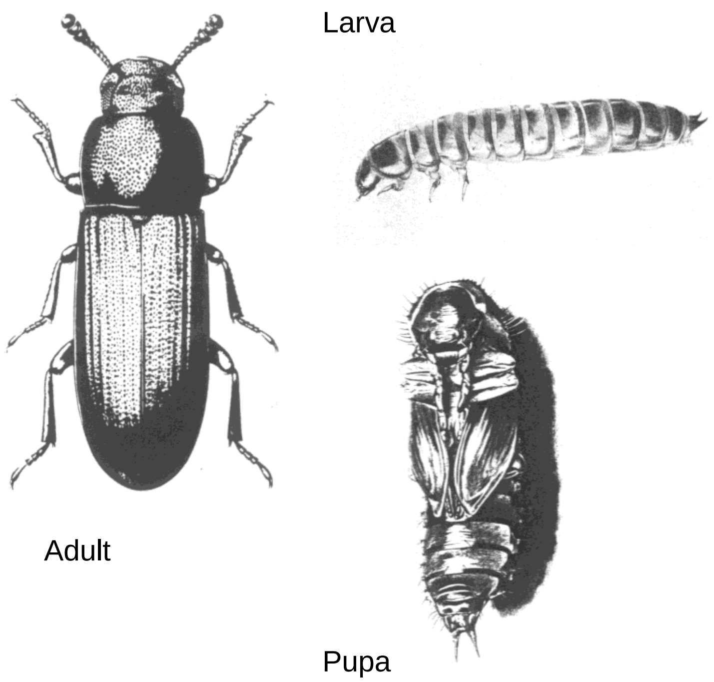

Figure 1.7 *Tribolium castaneum*, adult (life size 2.5-4.5 mm), larva and pupa

Under optimum conditions (33-35°C at about 70% rh) adults live for many months. Throughout their lives females lay eggs loosely among their food and the larvae feed and complete their life cycle without necessarily leaving the food commodity. Development can be very quick (about 30 days) and population growth is very rapid.

Heavy infestations by *T. castaneum* and related beetles can produce disagreeable odours and flavours in commodities due to the production of chemicals called quinones from the abdominal and thoracic defence glands of the adults. Flour exposed to *T. confusum,* at 100 adults/kg for three weeks, showed a distinct change in viscosity and extensibility when made into dough. Tumours have been observed in mice that had been fed flour on which an initial population of *T. castaneum* at 20 adults/kg had been allowed to develop for one year. However, quinones did not appear to accumulate on milled rice. It was concluded that flour absorbed quinones probably due to its finely divided nature while solid semi-crystalline grains do not.

At least ten other species, very similar in appearance to *T. castaneum,* are found in farm and central stores. As *T. castaneum* is a very well known insect, these other species are often mis-identified as *T. castaneum.*

***Cryptolestes* spp.**	**2^{ary} beetle pests of cereals and pulses**

Several species of *Cryptolestes* are common in mills and stores where they are secondary pests of cereals, nuts, oilcakes, dried fruit and other commodities. The adults are small (2-2.5 mm), elongate, very flat light-coloured beetles with long thin antennae (Fig. 1.8).

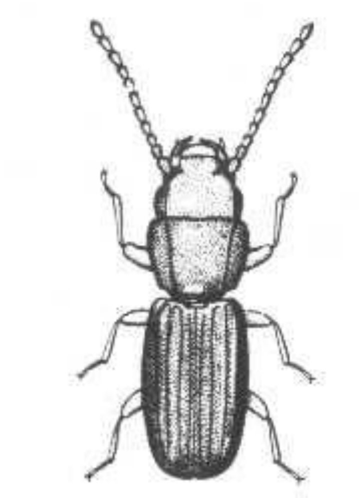

Figure 1.8: *Cryptolestes* sp, adult (life size 2-2.5 mm) and larva

Small larvae of *Cryptolestes* spp. may enter cereal grains at points of minor damage, especially in wheat where the embryo is often exposed. The embryo of cereals is often attacked preferentially. *Cryptolestes* spp. prefer high moisture content food and the presence of large numbers may indicate moisture problems.

Oryzaephilus spp.	2^{ary} beetle pest of cereals and pulses

Oryzaephilus spp. are moderately small (2.5-3.5 mm) rather flat, parallel-sided beetles, which are distinguished by six large tooth-like projections on each side of the body (Fig. 1.9).

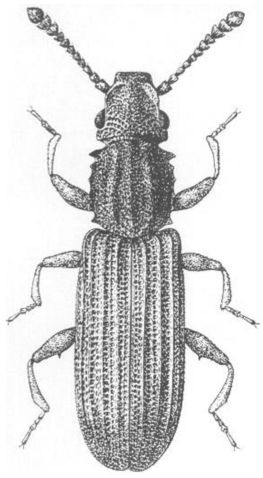

Figure 1.9: *Oryzaephilus surinamensis* (life size 2.5 - 3.5 mm)

There are two common species, *Oryzaephilus surinamensis* and *Oryzaephilus mercator*, which are similar in appearance but differ biologically. *Oryzaephilus surinamensis* develops more quickly than *O. mercator* at high temperatures and humidities (35°C, 90% rh) and is more tolerant than *O. mercator* of extremely high and low temperatures and humidities.

Both species attack cereals, cereal products, oilseeds, copra, spices, nuts and dried fruit. However, *O. surinamensis* is most successful on starchy, cereal diets, while *O. mercator* prefers diets with a high oil content (e.g. rice bran, groundnuts etc).

Cadra cautella	2^{ary} moth pest of cereals and pulses

Cadra cautella (Fig. 1.10) is a common and important secondary pest of cereals, cereal products, cocoa, dried fruit, nuts and many other commodities. In newly-emerged adults the fore-wings are greyish-brown in colour, with an indistinct pattern. Older specimens which have lost most of their scales are dull grey in colour.

Adult C*. cautella* are fairly short-lived (usually 7-14 days) and do not feed. The females lay their eggs loosely on the surface of the commodity. The larvae move extensively through the produce as they feed and, as they move about, they spin copious quantities of silk, called webbing. The webbing from heavy infestations can mat together the commodity and render it unfit for consumption.

Last instar larvae move out of the produce and wander about freely until they find a suitable site for pupation. Pupation sites are usually cracks, crevices and frequently the gaps between grain bags.

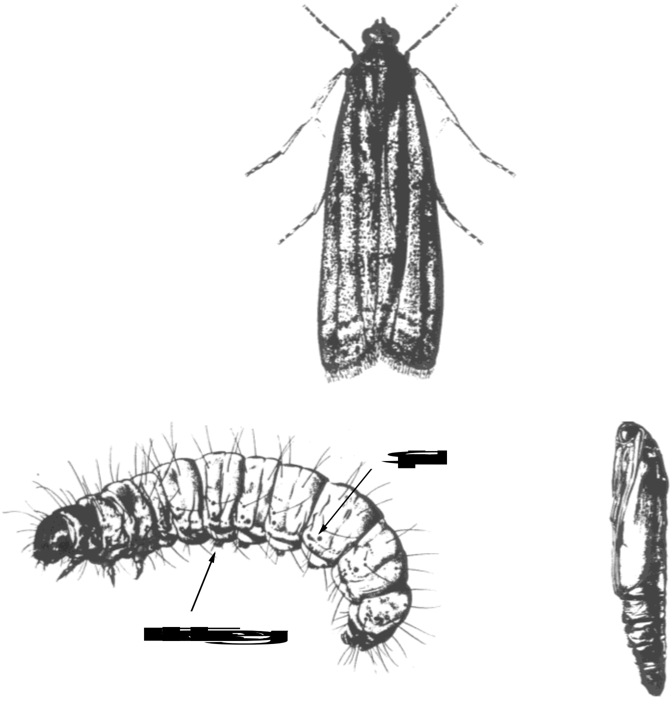

Figure 1.10: *Cadra cautella,* adult (wing span 11-28 mm), larva and pupa

Newly-emerged adults can mate within a few hours of emergence, and eggs are laid soon afterwards (usually within 24 hours of emergence). The female moths produce a scent (called a pheromone) that attracts males for mating.

Adult *E. cautella* usually remain at rest during daylight. The peak periods of flight are around dawn and dusk. Egg laying behaviour follows the same rhythm.