## 1. INTRODUCTION

Losses occurring in feedstuffs during storage fall under four major categories:

(a) weight loss,
(b) quality loss,
(c) health risk, and
(d) economic loss.

These losses arise from the foraging activities of insects, micro-organisms and animals; improper handling; and, physical and chemical changes, all of which are interrelated. Storage loss in a feed mill is primarily due to material eaten or destroyed by insect and animal pests and fungi. When serious infestation by these pests occurs there is extensive weight loss accompanied by damage to quality. Intense insect activity often results in mould growth which not only completes the destruction of the feedstuffs but also poses serious health risks to animals or fish feeding on rations containing damaged feed ingredients.

The first three categories of storage loss are of primary concern to the compound feed manufacturer. Weight loss due to loss of moisture content or to the presence of a large insect population in stored feed is problematic in developing countries where post-harvest handling and processing are often improperly conducted. Ineffective enforcement of quality standards (if, in fact, such standards exist) results in the production and supply of inadequately processed feed ingredients which often are more susceptible to deteriorative processes. The lack of quality standards reflects the relative unimportance attached to aesthetic considerations in commercial transactions of feed commodities in these countries. Hence, economic loss which we shall define here as the cost incurred in inspection, prevention, and control to maintain quality standards (although considered to be of overriding importance in most industrialized countries) is superseded by the other three major categories of storage losses in developing countries.

This chapter looks at the effects of insects and micro-organisms and the deteriorative changes that result from their presence in stored ingredients in feed mills in the tropics.

## 2. INSECTS

[2.1 Factors Affecting Insect Infestation of Feedstuffs](http://www.fao.org/docrep/x5738e/x5738e0e.htm#2.1 factors affecting insect infestation of feedstuffs)
[2.2 Feeding Habits of Insects](http://www.fao.org/docrep/x5738e/x5738e0e.htm#2.2 feeding habits of insects)
[2.3 Losses Due to Insect Attack](http://www.fao.org/docrep/x5738e/x5738e0e.htm#2.3 losses due to insect attack)
[2.4 Control](http://www.fao.org/docrep/x5738e/x5738e0e.htm#2.4 control)

Insects feed on most feed ingredients and contaminate them with faeces, webbing, body parts, foul odours, and micro-organisms. Beetles and moths are the most destructive of the grain insects, and many are capable of destroying an entire store of feed. Table 1 lists some of the most common insect pests responsible for the destruction of feedstuffs in storage.

### 2.1 Factors Affecting Insect Infestation of Feedstuffs

The occurrence and development of an insect infestation is dependent on many factors such as source of insects, available food, temperature, moisture, air, condition of the feed-stuff, presence of other organisms, and the efforts to exclude or kill the pests. Major factors affecting population growth of most insect species are: temperature, relative humidity, and moisture content of the feed ingredient. The nutritive content and certain physical properties of feeds will also determine the vulnerability of such materials to attack. Only a few insect species are able to attack sound kernels of feed grains. High moisture content (16 percent or more) renders feed grains soft and susceptible to attack. Meals pressed into cakes or hard flakes are more resistant. Insects appear to eat small particles more readily than large ones.

**Table 1 Environmental Constraints of Major Insect Pests Infesting Feedstuffs**

|  |  |  |  |
| --- | --- | --- | --- |
| **Species** | **Susceptible feedstuffs** | **Minimum for increase to epidemic numbers** | **Optimum range for increase** |
| **Scientific name** | **Common name** | **Temp, °C** | **Rel. Hum, %** | **Temp, °C** |
| Sitophilus spp. | Weevils | Cereal grains | 15 | 50 | 26-30 |
| Sitotroga cerealella | Grain moth | Cereal grains | 16 | 30 | 26-30 |
| Tribolium spp. | Flour beetles | Cereal grains and cereal by-products, oilseed cakes and meals, finished feed | 21 | \* | 30-33 |
| Oryzaephilus spp. | Saw-tooth grain beetles | Cereal grains and cereal by-products, oilseed cakes and meals, finished feed | 21 | 10 | 31-34 |
| Cryptolestes spp. | Flat grain beetles | Cereal grains and cereal by-products, oilseed cakes and meals, finished feed | 21 | 50 | 30-33 |
| Cadra cantella | Tropical warehouse moth | Cereal grains and cereal by-products, oilseed cakes and meals, finished feed | 17 | 25 | 28-32 |
| Rhizoperthadominica | Lesser grain borer | Cereal grains, pulses, dried roots | 23 | 30 | 32-35 |
| Trogodermagranarium | Khapra beetle | Cereal grains and cereal by-products, oilseed cakes and meals, finished feed, pulses | 24 | \* | 33-37 |

\* Species breeding rapidly even in driest conditions
(Sources; Howe, 1965; Cockerel 1 et al, 1971)

2.1.1 Temperature

All insects attacking stored feedstuffs have an optimum zone of temperature at which populations increase most rapidly (Table 1). Most of the important insect pests are tropical species with an optimum temperature of about 28°C. It is, therefore, evident that losses from insect infestation will be greatest in the tropics.

2.1.2 Relative humidity

As a rule, relative humidity affects the rate of population increase in insects less dramatically. Up to 70 percent relative humidity, there is progressive increase in insect multiplication. Beyond 70 percent relative humidity, mould formation sets in and complicates the situation. The moisture content of feedstuff is closely related to the relative humidity. A low moisture content coupled with low humidity will provide protection against insect infestation.

### 2.2 Feeding Habits of Insects

Some insects are not discriminatory in their feeding habits whereas others are highly selective in their choice of the parts of a feed ingredient eaten. For example, moth larvae generally feed on or near the surface of the grain mass; beetles are destructive throughout. Most larvae spread silk webbing over the surface of feed grains and their by-products, making them not only unsightly but also creating handling and processing problems as well.

Insect infestations sometimes cause excessive heating of grain. When the insect population reaches a certain density, their metabolic activities release more heat than can be dissipated. In localized areas where the insect population is extremely dense the temperature may reach 45°C. Associated micro-organisms, mainly fungi, may raise this to nearly 75 °C, causing extensive spoilage and, occasionally, spontaneous combustion.

### 2.3 Losses Due to Insect Attack

The best warning of serious weight loss is the presence of a large insect population. This is easily identifiable in sacked grain by the appearance on the sack surface of frass resulting from feeding activity of the insects. High temperature, high humidity, softness, and high nutritive value of the feedstuff and storage in small quantities are all conducive to insect damage, but are often unavoidable. Loss may be aggravated by prolonged storage. Failure to keep the storage area clean and retention of infested sweepings will increase the liability of insect attack.

**2.3.1 Weight loss**

Weight loss in infested feed is not always evident unless it involves sacked grain or oil cakes when the appearance of frass on the surface of the sack points to the feeding activity of a large insect population.

**2.3.2 Quality loss**

For the feed manufacturer, one of the most important considerations of insect attack on feedstuffs is the loss of quality. The effects on quality are various. Most stored feed material undergo some chemical changes that alter their flavour and nutritive value. As well as eating some of the feed, insect pests tend to accelerate these harmful chemical changes. Secretion of enzyme lipase by the insects themselves will enhance deteriorative chemical processes. Few stored feedstuffs are homogeneous and insects and mites are known to select those parts or particles of feed they prefer.

Many feedstuffs contain a high percentage of fat which tends to break down during storage. This breakdown is accelerated by insect attack, especially when the insects break off small particles, introduce micro-organisms, or raise the temperature or moisture content. Evidently, the insects use the fat in the material they eat. The breakdown of fat causes an increase in free fatty acids which cause off-flavours. The free fatty acid involved in product rancidity is assumed to be oleic acid, and the quantities released is a result of oxidation of fats in certain feedstuffs are quite substantial.

The subject of lipid oxidation will be further discussed when the deteriorative changes taking place in stored feedstuffs are considered.

Scavenging insects, such as cockroaches, may cause contamination with pathogenic bacteria such as Salmonella.

### 2.4 Control

Climate is the most important factor determining the effectiveness of a storage system for feed ingredients because of the close relationship between insect growth and ambient climatic conditions. An important relationship also exists between insects and micro-organisms in stored feedstuffs.

Total eradication of insect populations from tropical warehouses for feed ingredients is not possible. The degree of infestation can, however, be brought to manageable proportions through a programme of vigilance and effective control measures. Heavily infested ingredients should not be brought into the store. Infested material, if accepted, should be kept separate until fumigated (this is to be done as soon as possible) to totally eradicate the pests.

Good house-keeping involving the sweeping up of spilled material will check scavenger insects as well as rodents which may carry insects in their fur.

## 3. MICRO-ORGANISMS

[3.1 Factors Affecting Fungal Growth in Feedstuffs](http://www.fao.org/docrep/x5738e/x5738e0e.htm#3.1 factors affecting fungal growth in feedstuffs)
[3.2 Detrimental Effects of Storage Fungi on Feedstuffs](http://www.fao.org/docrep/x5738e/x5738e0e.htm#3.2 detrimental effects of storage fungi on feedstuffs)
[3.3 Control](http://www.fao.org/docrep/x5738e/x5738e0e.htm#3.3 control)

Micro-organisms are biological contaminants of the natural environment and are present in all feedstuffs. They persist after crops have been harvested from the fields and in animal carcasses prior to rendering. Because bacterial and field fungi do not thrive at moisture levels below 20 percent, post-harvest processing of commodities and animal renderings involving heat, chemical and mechanical extraction, and dehydration eliminate most of the original contaminating microflora. Fungi spores, which are resistant to harsh processing treatment, may remain dormant in the processed feedstuff until more favourable conditions once again permit their proliferation.

### 3.1 Factors Affecting Fungal Growth in Feedstuffs

Recontamination of feedstuffs by adventitious micro-organisms during storage is of primary concern to the feed processor. Adventitious storage fungi grow at moisture content (15 to 20 percent) in equilibrium with a relative humidity of 70 to 90 percent and are considered the principal spoilers of feedstuffs in storage. When the relative humidity falls below 65 percent no growth occurs.

Under favourable conditions, fungi can raise the temperature in their immediate environment to 55 C with con commit tent increase in moisture content of the affected feedstuff to as high as 20 percent. When this occurs, secondary spoilage by bacteria takes place.

The most common fungi involved in the spoilage of feedstuffs belong to the Aspergillus spp. and the Penicillium spp. These grow at temperatures up to 55 C and at a minimum, relative humidity of 65 percent. They are most destructive when temperatures exceed 25 C and relative humidity exceeds 85 percent.

### 3.2 Detrimental Effects of Storage Fungi on Feedstuffs

The chief effects of storage fungi on feedstuffs are:

(a) mycotoxin production,
(b) heating,
(c) moisture increase, and
(d) mustiness (staleness).

3.2.1 Mycotoxin production

Mycotoxins are compounds produced by fungi growing in infested agricultural commodities. They are toxic to both humans and animals. The aflatoxins, a group of highly toxic and carcinogenic metabolites produced by Aspergillus flavus are perhaps the most important among mycotoxins contaminating feedstuffs. Transmission of the toxin to milk, meat, and eggs through farm animals feeding on contaminated feed poses an increasing health hazard. Studies on the toxicity of aflatoxin to fish have not been extensive but toxicity to trout (oral LD50: 0.5 mg/kg body weight) is comparable to toxicity to ducklings, the latter recognized as the most susceptible animal to aflatoxin poisoning (see Table 2).

**Table 2 Oral Toxicity of Aflatoxin to Various Animal Species**

|  |  |  |  |
| --- | --- | --- | --- |
| **Species** | **Age (weight)** | **Sex** | **LD50 in mg/kg body weight** |
| Duckling | 1 day | M | 0.37-0.56 |
| Trout | 100 g | M-F | 0.5 |
| Sheep | - | - | 2.0 |
| Pig | Weanling | M-F | 2.0 |
| Mouse | - | - | 9.0 |
| Rat | 1 day | M-F | 1.0 |
| 21 days | M | 5.5 |
| 21 days | F | 7.4 |

Feedstuffs known to be contaminated by A. flavus include: groundnut cakes, maize, sorghum, sunflower, cottonseed cakes, copra, and cassava. To produce aflatoxin, however, A. flavus must be present alone in a practically pure culture. The presence of other fungi, yeast, or bacteria seems to interfere with aflatoxin production. Crops such as peanuts, cottonseed, and copra are high aflatoxin risks precisely because A. flavus often infest them as a practically pure culture with few or no other microflora. In addition, the fungus produces the toxin in these crops at relatively low moisture levels, 9 to 10 percent, compared with 17 to 18 percent moisture for most feed grains. Feed grains such as maize and sorghum grown in the tropics, therefore, also pose high risk.

**3.2.2 Heating and moisture increase**

Mould growth in feedstuffs is accompanied by rising temperatures and moisture content. Aspergillus glaucus, which has a minimum moisture requirement of 14.5 percent, is the first significant species involved during mould infestation of feed grains. Temperature elevation that accompanies this initial attack flavours the proliferation of a second species, A. candidus, which raises the moisture level of the infested grain to 18 percent or higher. At such high moisture levels, A. flavusactivity becomes intense and total destruction of the wholesomeness of the feed grain becomes complete (see Figure 1).

Fungal activity in stored feed- grains is not often apparent until after serious damage is done. This is because such activity takes place not near the surface where temperature gradients produced by such activity are quickly abolished, but within the interior of the storage container. Silos for grains should, therefore, be equipped with temperature sensors to provide early warning of trouble. Similar preventive measures are not possible for bagged material. The common practice of storing bags of grains in large piles to minimize and control insect infestation actually promotes fungal activity, especially in the tropics. The "sweating" of bags within a large stack is evidence of serious fungal damage to the stored grain. The surface of such bags will feel warm to the touch, and when a hand is inserted into the grain, it will actually feel hot.

**3.2.3 Staleness**

Feedstuffs that are damaged by fungi tend to become lumpy. Feed grains suffer discolouration while damaged maize turns a dark brown with some blackened kernels being evident. The grain also exhibits a characteristic bluish sheen. Staleness or mustiness is another characteristic of commodities damaged by fungi.

### 3.3 Control

The prevention of mould contamination of stored feedstuffs depends mainly on the successful control of insect infestation, because the destructive activities of insects often create conditions favourable to mould; viz., increased moisture and temperature and the destruction of the protective hulls of feed grains expose their moist interiors. There is no effective way of eliminating mould, although effective measures have been developed to control their growth in compound feeds. These measures include the use of propionate and, more recently, gentian violet.

## 4. DETERIORATIVE CHANGES IN STORED FEEDSTUFFS

[4.1 Factors Affecting Deteriorative Processes](http://www.fao.org/docrep/x5738e/x5738e0e.htm#4.1 factors affecting deteriorative processes)
[4.2 Rancidity](http://www.fao.org/docrep/x5738e/x5738e0e.htm#4.2 rancidity)

Most stored feedstuffs undergo some chemical changes altering flavour and nutritive value. These changes are usually deteriorative in nature and are associated with the lipid content of the feedstuffs. Lipids tend to break down during storage into free fatty acids.

### 4.1 Factors Affecting Deteriorative Processes

**4.1.1 Environmental factors**

Environmental factors that determine the extent of deterioration of stored feedstuffs also affect the rate of growth of its insect and microbial population. These include ambient temperature and relative humidity. Other environmental factors relate to the general cleanliness of the storage areas and to design features of the storage building; e.g., protection against rain and insulation against scavenger pests.

**4.1.2 Insects and micro-organisms**

The role that insects and micro-organisms play in the breakdown of lipids in the feedstuffs they attack has been discussed earlier. The increase of fatty acids as a result of lipid breakdown is of particular importance in the storage of fish meal, cereal brans, and oil seed derivatives; e.g., copra, groundnut, and palm kernel meal. This increase in free fatty acids in improperly stored feedstuffs results in rancidity.

[**Fig. 1 Moisture-temperature relationship and the destructive activity of Aspergillus in stored grain**](http://www.fao.org/docrep/x5738e/x5738e35.gif)

### 4.2 Rancidity

There are three major chemical processes that give rise to rancidity: oxidation, hydrolysis, and ketone formation. Due to the relative unimportance of the other two processes in stored feedstuffs only oxidation of fats will be described here.

**4.2.1 Lipid oxidation**

Rancidity resulting from lipid oxidation is the most important deteriorative change occurring in stored feedstuffs. Feedstuffs containing lipids which are highly unsaturated (e.g., rice bran and fish meal), are especially susceptible to oxidation. The mechanism of lipid oxidation begins with auto-oxidation involving the direct reaction of lipids with molecular oxygen to form hydroperoxides. This is followed by secondary reactions yielding diperoxides if further oxidation takes place, or ketoglycerides if the hydroperoxides are dehydrated. Fission of hydroperoxides yield products containing carbonyl and hydroxy groups which will react further to form other products. Oxidation of carbon-carbon double bonds in other molecules gives rise to epoxides and hydroxy glycerides. These products of secondary oxidation of lipids contribute to 'off flavour' and include toxic compounds frequently-associated with rancidity. Furthermore, carbonyl groups produced by the fission of aldehydic hydroperoxides can react with the epsilon - amino group of lysine, thereby reducing the nutritive value of the protein.

**4.2.2 Factors affecting lipid oxidation**

The chief factors increasing the rate of lipid oxidation in stored feedstuffs are as follows:

(a) enzymes

the presence of lipoxidase and perhaps other enzymes as well

(b) hematin

this factor is important in the storage of fish and meat meals

(c) peroxides

these compounds which are themselves products of auto-oxidation of lipids catalyze the oxidation of lipids

(d) light

ultra violet light is involved in the photolysis of peroxides

(e) high temperature

in general, the higher the storage temperature the more rapid the breakdown of lipids

(f) trace metal catalysis

many metals, notably iron, copper, cobalt, and zinc accelerate lipid oxidation. Iron and copper does this by direct electron transfer in redox reactions, while zinc induces the breakdown of hydroperoxide to free radicals.

Lipid oxidation can be inhibited by adding compounds known as anti-oxidants. Two commonly used feed anti-oxidants are ethoxyquin and butylated hydroxytoluene which sequester free radicals formed during oxidative processes. Cereal grains contain effective quantities of natural anti-oxidants (e.g. tocopherols) which impart considerable stability to their lipid contents, unless the kernels are damaged by storage pests.

**4.2.3 Feedstuffs especially susceptible to lipid oxidation**

Fish lipids are especially susceptible to oxidation due to the greater chain lengths of the fatty acids and the greater number of unsaturated carbon-carbon bonds along the fatty acid chains. Storage of fish meal is problematical, due to the frequent occurrence of exothermic oxidation which could lead to spontaneous combustion. The heat generated also leads to amino sugar reactions which lower the digestibility of protein. Most fish meals marketed commercially contain added anti-oxidant to inhibit lipid oxidation and thus reduce the risk of fire during sea transit and prolonged storage under unfavourable ambient conditions.

Other feedstuffs which have storage problems associated with high lipid content are rice bran and expeller oil cakes with high residual oil content. Among the latter, the most susceptible are copra cake and palm oil cake. This is due to the significant levels of unsaturated fatty acids in coconut and palm oil. The lactose contained in milk powder has a tendency to react with loosely associated milk proteins to form melanoids in the Maillard reaction. These sugar-protein compounds have very low digestibility.

## 5. STORING FEEDSTUFFS

Some weight loss of feedstuffs during storage is unavoidable. The extent of loss is affected by:

(1) the general hygiene of the store, because that determines whether or not insects can breed in the buildings away from the produce;

(2) the turn-over of the goods, because they determine the length of storage;

(3) the way in which waste and odd lots are handled which determines whether or not large foci of infestation can develop in neglected produce; and

(4) the size of stacks and the closeness of packing. Most insect species are confined, more or less, to the surfaces of a stack, and weight loss is usually highest at the periphery.

Sometimes, especially in the tropics and in imported produce, materials are infested before stacking. If the core of the stack is infested from the start of storage, then the heat of metabolism of the insects will raise the temperature in the core and, hence, the rate of increase of the insect population and the amount of damage done.

If the stack is small and much of the heat is dissipated, the temperature will remain favourable for insects and weight loss will be very great. If the stack is large, the accumulated heat in the core will get too hot for the insects. After that, weight loss will occur only at the outside of the stack. For this reason, large stacks are advocated in the tropics. However, the high temperature has harmful effects that must be set against prevention of weight loss. Continuous high temperature accelerates chemical degradation, especially for vitamin destruction and the development of rancidity.

## 6. REFERENCES

Cockerell, Y., B. Francis and D. Halliday, 1971 Changes in nutritive value of concentrate feeding-stuffs during storage. In Proceedings of the Conference on the development of feed resources and improvement of animal feeding methods in the CENTO region countries. London, Tropical Products Institute, Pp. 181-192,

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**Some important tips related to feed quality, feed storage, and feed loss management include:**

* + Analyze incoming ingredients and use selected suppliers that have quality control programs.
	+ Always monitor ingredients moisture.
	+ Use either a Koster Tester, a microwave oven, or a forced-air oven to check ration and ingredients moisture.
	+ Keep daily or weekly inventory reports.
	+ Check incoming ingredients moisture, color, odor, and texture.
	+ Watch for the presence of foreign material, heat damage, mold, and spoilage.
	+ Establish rejection criteria for incoming ingredients to ensure the best ration possible.
	+ Keep written quality control targets.
	+ Always handle feeds in a way that ensures that contamination does not occur.
	+ Frequently sample both ingredients and the total mixed ration.
	+ The ration should be consistently mixed.
	+ Check if the feed analysis matches the ration formulation.
	+ The mixer scale should be checked periodically for accuracy.
	+ Bunker forages should be tightly packed to minimize spoilage.
	+ Recognize that coproducts (e.g., distillers grain) will vary in nutrient content. A regular testing program should be established for coproducts used.
	+ Water must be kept clean.
	+ Reduce bunk shoveling with good bunk management.
	+ Estimate and account for feed waste.
	+ Watch the bunks to minimize feed wastage resulting from sorting or climatic factors (e.g., rain, snow).
	+ In times of high feed costs, reducing feed waste does make a difference.