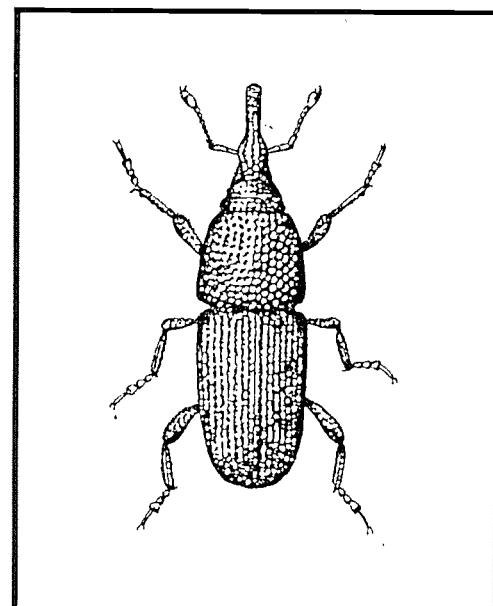
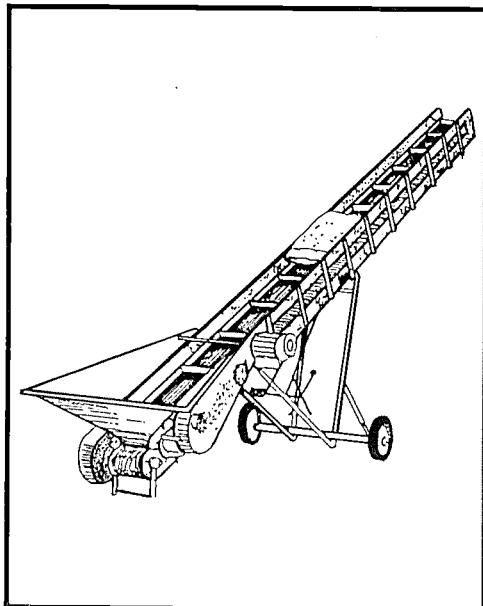
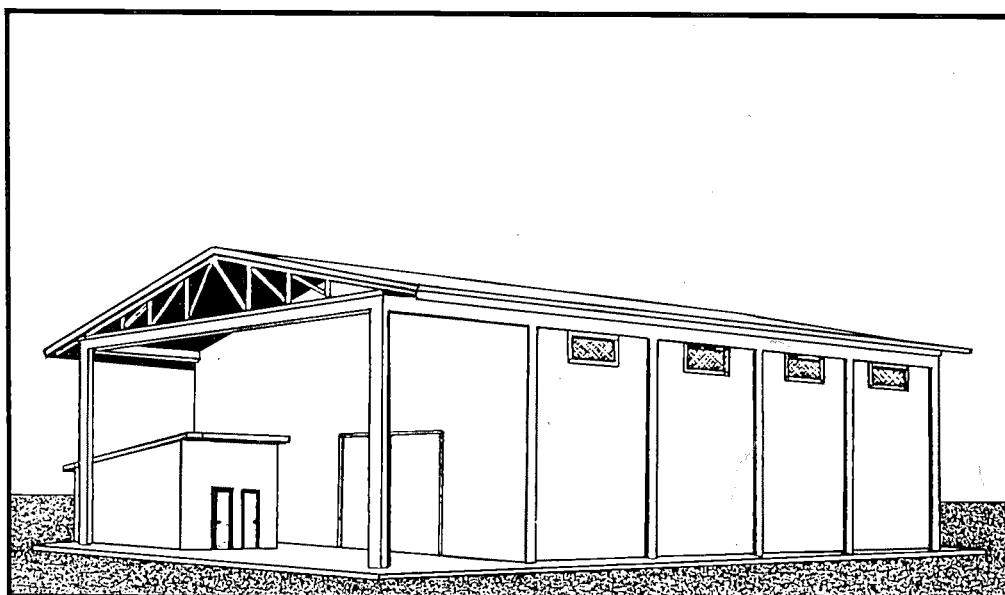


Agricultural engineering in development: warehouse technique

FAO
AGRICULTURAL
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BULLETIN

74



FOOD
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by

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English translation

G.G. Corbett



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CHAPTER 1

INTRODUCTION

In the post-harvest sequence, storage constitutes the essential phase between crop harvesting and use of the crop for direct consumption or first processing. Grain storage is of paramount importance, especially for the developing countries where food grains still constitute the staple food of the human diet.

Storage periods, methods and role vary depending on the country, the climate and the crop involved but mainly according to the social and economic levels concerned; these are generally referred to as follows:

- Producers, who practise storage to satisfy their own food needs between harvests, and to save seed.
- Traders, to supply the market according to the demand.
- Food industries, which process grain for human or animal food.
- Government and agencies entrusted to control grain flow on the market so as to assure steady food supplies for consumers, and price stabilization.

At every level, stored products are subject to losses that may occasionally be very heavy. The construction of appropriate storage structures, of a good design, conveniently equipped and perfectly managed on the one hand and, on the other, the observance of strict standards of hygiene in stores, and efficient pest control constitute the actions that must jointly be conducted to limit storage losses.

The present document deals with the techniques of food grain storage in warehouses with capacities between some hundreds and several thousand tonnes.

The work begins with a review of the main characteristics of grain and the different factors likely to induce grain deterioration during the storage period. A brief description of deterioration processes is given.

The following chapter deals with sampling problems and of grain quality, considerations which in practice are frequently disregarded whereas they are essential and should be considered prior to any action.

Chapter four constitutes a more technical part concerned with storage structures and especially the design and construction of new warehouses and the transformation of existing ones into appropriate storage structures and with the equipment and management of storage centres.

Finally, chapter five deals with the control of the main pests found in stored produce i.e. insects and rodents, and gives a description of the main control methods presently applied.

CHAPTER 2

GRAIN STORAGE

Physical and biochemical characteristics of grains, their physical properties and ability, as living organisms, to react to environmental conditions must all be borne in mind in approaching storage problems and understanding deterioration processes occurring in stored produce.

A. GRAIN CHARACTERISTICS

1. Physical structure of grains

Grains are composed of three parts i.e., the covering, the endosperm and the germ.

(a) Covering

Whereas pulses are real seeds, generally with two seed coats, cereal grains are fruits (called caryopses) with the outer covering, or pericarp, adhering to the seed. This covering that protects the seed and reduces exchanges with the outside environment can, nevertheless, be penetrated by microorganisms (moulds) and gases. Some cereal grains still have floral coverings adhering to the grain even after threshing. Such is the case of paddy rice covered with husks (glumes). These cereal grains are consequently called "dressed" ones. On the contrary, cereal grains without husks (maize, sorghum, wheat) are called "bare" cereal grains. These are consequently more directly exposed to mechanical impact and attacks from outside (mould, insects).

Figure 1 shows the structure of a maize grain ("bare" cereal grain) and Figure 2, the structure of a paddy grain ("dressed" cereal grain).

(b) Endosperm

It constitutes almost the whole inner part of the grain and represents the carbohydrate storage element (starch). In cereal processing operations, flour and semolina are obtained from the endosperm, and bran from the grain covering (or pericarp). It consists of starch granules aggregated in a peripheral aleurone layer. The arrangement of starch granules gives the endosperm a more or less brittle and soft floury or hard horny texture. Finally, some pulses (beans and peas, for example) are without endosperm because, as the seed develops, the endosperm is rapidly absorbed by the cotyledons and thus become the storage elements.

(c) Germ

In the cereal grains the germ consists of the embryo that is the rudiment of the future plant, and of the scutellum (or cotyledon) and assures exchanges between the embryo and the endosperm. Depending on the cereal grain concerned, the germ size varies in relation to the

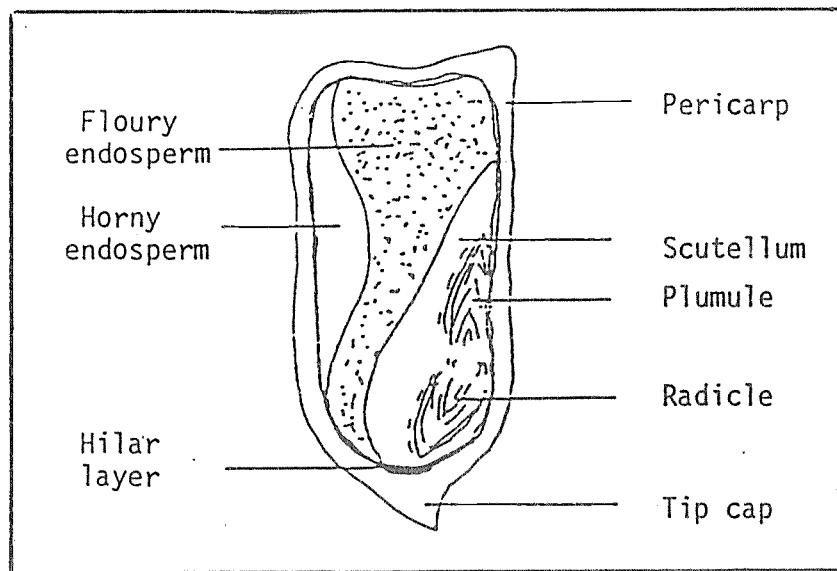


Figure 1: Structure of the maize grain

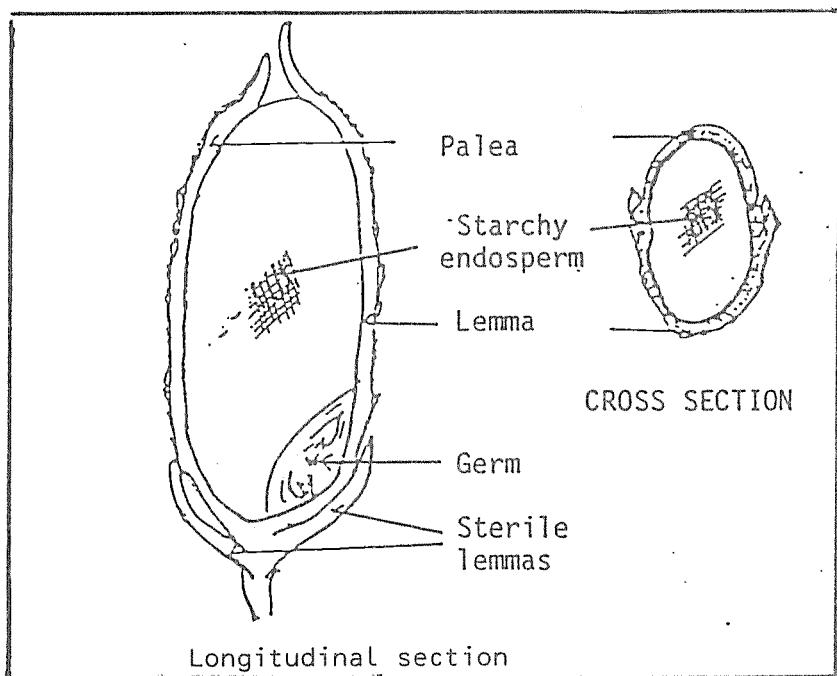


Figure 2: Structure of the rice grain (paddy)

total grain size. It is relatively big, and consequently brittle, in maize where it corresponds to 11 percent of the grain, whereas it only corresponds to 2 percent of the husked rice grain. As the germ is rich in proteins and fats (lipids) it assures important nutrient supplies. It obviously plays a fundamental part as far as seeds are concerned.

2. Biochemical composition of grains

Grains comprise dry matter and water.

i. The dry matter consists of ash (or mineral matter) and organic matter composed of carbohydrates, lipids, proteins and vitamins.

Carbohydrates, also called "sugars" are chiefly found in the endosperm as starch granules. From a nutritional standpoint they mainly provide energy.

Lipids, sometimes called "fats" are generally concentrated within the germ and also mainly constitute an energy source. When storage conditions are bad, lipids oxidize, developing a rancid odour and flavour in the grains.

Proteins are mainly found in the germ and the aleurone layer. Cereal grains are not rich in proteins, but pulses are richer.

Vitamins are complex chemical elements found in minute amounts in grains but that are essential from a nutritional viewpoint because they act at the level of the fundamental functions of the human organism. Everybody knows that a vitamin lack can cause severe troubles. Cereal grains and pulses offer important supplies of vitamin B in food. These vitamins are especially concentrated within the germ and the pericarp (grain covering). When storage conditions are bad (high temperature, insect infestation) vitamin losses in stored grain can be heavy.

ii. Water is present in grains in different forms as follows:

- water of composition, which is closely combined with the grain,
- absorbed or "free" water, (obviously, not closely combined with the grain).

The presence or not of such free water, which is readily usable by developing microorganisms, will largely determine the "storability" of the grain.

The moisture content (mc) is the ratio in percent of the weight of moisture contained in a sample to the total weight of the sample.

$$\% \text{ moisture content} = \frac{\text{weight of water}}{\text{(wet basis)}} \times 100$$

For example if 50 kg of grain contains 10 kg of water, the grain moisture content is 20 percent:

$$(\% \text{ mc} = \frac{10}{50} \times 100)$$

Techniques for measuring grain moisture content are described in annex 2.

3. Physical properties of grains

(a) Porosity: grain in mass constitutes a porous material in which 30 to 40 percent of the volume consists of intergranular air. Such porosity allows air to enter through the grain mass (ventilation-drying).

(b) Thermal conductivity: thermal conductivity of grains is very low, that is they resist heat transfer, acting as heat insulators. When local heating occurs during storage, the heat so produced dissipates very slowly and results in a high local temperature rise called "hot spot". This can be removed only by ventilation or unloading.

Finally, due to such low thermal conductivity the high diurnal temperature difference that can be observed in some areas has therefore little effect on the mass of stored grain. Nevertheless, it should be noted that, in non-ventilated structures (flexible silos, fumigated stores) such a temperature difference can generate condensation, and consequently encourage mould-formation, on the surface of stored grain.

(c) Hygroscopicity: grains constitute a hygroscopic material i.e. they exchange water (vapour) with the surrounding air. We saw before that grains contain liquid water and, on the other hand, we know that air contains water vapour. Depending on the conditions involved, moisture exchanges take place between air and grains. So, dry grains in contact with humid air are going to absorb moisture and increase their moisture content, whereas humid grains in contact with dry air are going to release moisture into the air and so to dry. Such exchanges gradually develop to equilibrium: hygroscopic equilibrium or equilibrium moisture content.

B. FACTORS OF GRAIN DETERIORATION

1. Respiration: sign of grain activity

Grains are living organisms and as such they respire. The respiration mechanism can be roughly represented by the breakdown of starch which in contact with oxygen generates carbon dioxide, water vapour and heat.



Such breakdown is a self-accelerating process: the higher heat and moisture content are, the more the grain respires. Such reaction is most frequent in stored masses of wet grain where it rapidly results in

a high increase in temperature, mould development and aggregation of grains. When this becomes so evident, it reveals very bad conditions of storage. To achieve safe storage conditions it is necessary to reduce the process to a minimum, by controlling the main physical factors of deterioration i.e. temperature and moisture.

2. Physical factors of grain deterioration

(a) Temperature

Temperature greatly affects storage of grains because it increases the respiration rate and consequently the breakdown process in stored products. It is generally accepted that the heat release within a mass of grain doubles for each 5°C increase in temperature, up to about 28°C ; above this temperature the effect slows down. In other words it can be considered that a batch of grain stored at 25°C will deteriorate twice as fast as if it was stored at 20°C , with all other conditions being equal. It is therefore essential to store food grains at the lowest possible temperature.

Temperature also influences the development of microorganisms (mould, for instance) and insects. Their optimum growth can be observed between 25 and 35°C which corresponds to a temperature range commonly found in stored products under tropical conditions. Finally regarding seeds, temperature must be controlled efficiently to preserve germination capacity, which is destroyed at temperatures over 40°C for cereal grains, and 35°C for oil seeds.

(b) Moisture

Moisture is certainly the major factor in grain deterioration. It increases the respiration rate of grains and hastens their internal breakdown. It is generally accepted that the heat release within a mass of grain doubles for each additional 1.5 percent increase in the grain moisture content.

So, for a given temperature, it can be considered that grain stored at 15 percent moisture content deteriorates twice as fast as grain stored at 13.5 moisture content.

Figure 3 illustrates the effect of temperature and moisture factors on the storage period. It can be noted that at a temperature of 25°C , grain stored at 13.5 percent moisture content can be safely stored for 80 days (point A) whilst at 15 percent moisture content the safe length of time for storage decreases to 30 days (point B). It can also be noted that the same grain at 15 percent moisture content can be preserved for 100 days if stored at 15°C (point C) instead of 25°C . The major effect of moisture, above a certain moisture content level, is to encourage moulds. This level is the critical limit for bad storage.

For a better understanding of the relationship between moisture and grain deterioration, it is essential to recall the concept of equilibrium moisture content. When grain and ambient air are in contact for a long time they reach an equilibrium state characterised by a same temperature and same water vapour pressure. When there is no

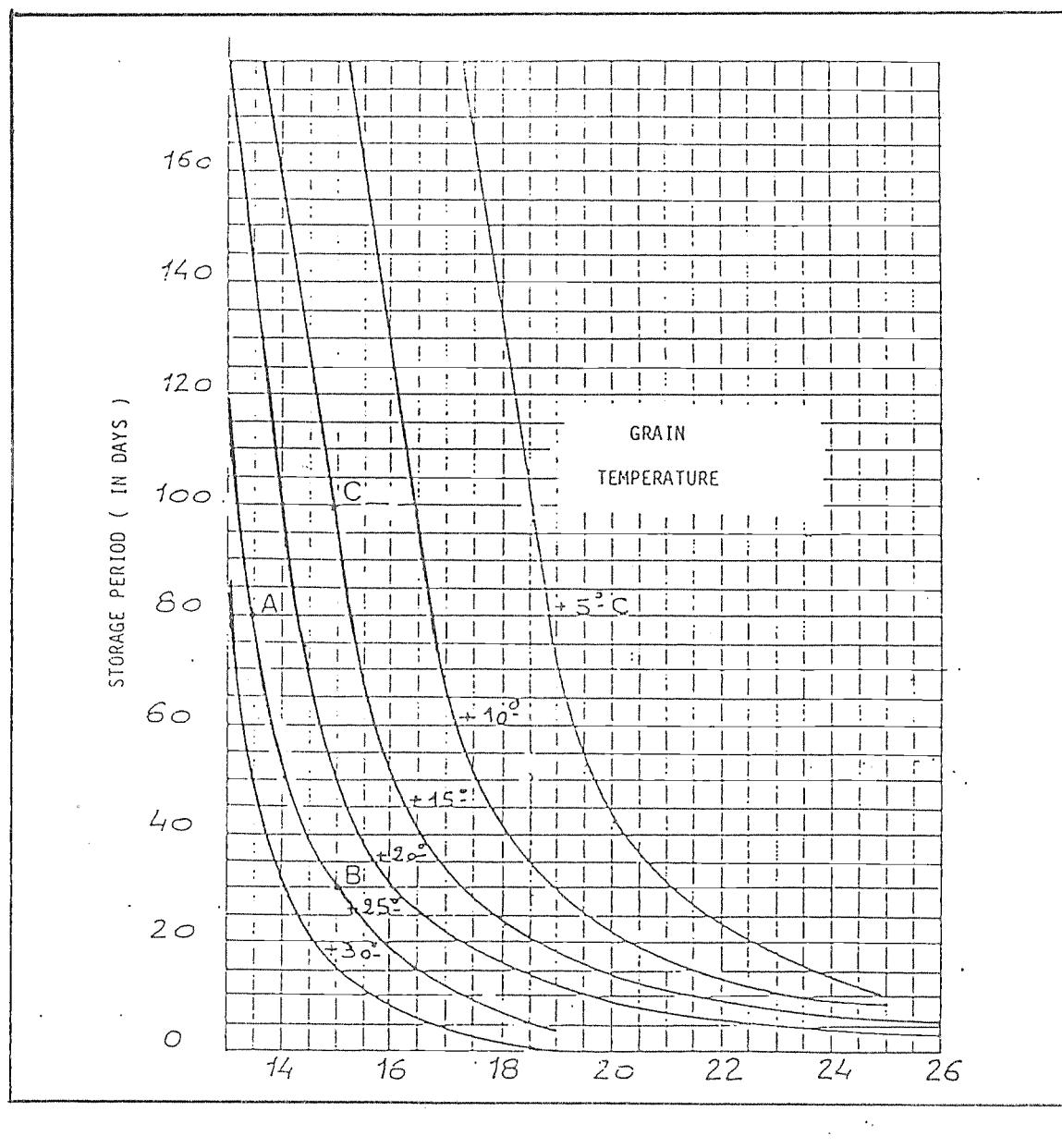


Figure 3: Storage length of time according to temperature and moisture content of grains (from: Agena, Bewer and Kosmina)

(The reference standard of safe storage considered to establish the diagramme is the germination capacity)

Example 1. – question: what is the length of time grains can be stored at 20°C and 13.5%mc?
answer: 140 days.

Example 2 – question: what is the length of time grains can be stored at 30°C and 15.5%mc?
answer: 10 days.

balance between the moisture in the grain and in the air, moisture moves from the grain to the air or reverse until there is a new equilibrium. For each relative humidity of air there is a corresponding grain moisture content value. Such equilibrium state can be represented by a curve called equilibrium curve characteristic of each product for a given temperature. Figure 4 shows equilibrium curves for maize at different temperature.

With air at relative humidity between 25 and 60 percent grain breakdown processes are considerably slowed down. It is only above 65-70 percent relative humidity of air that moulds develop and breakdown processes are hastened. For safe storage and specially to prevent mould development, grain moisture should be below the moisture corresponding to equilibrium with air at 70 percent relative humidity.

Table 2/1. Maximum acceptable moisture content for grain storage in hot areas

Produce	Grain moisture content (%)
Maize	13
Paddy	13-14
Rice	13
Sorghum	13
Millet	15
Wheat	13
Beans	14
Soyabbeans	12
Groundnuts	7
Cocoa	7

For long-term storage (e.g. reserve storage) the values can be reduced by 1 point.

(c) Combined effect of temperature and moisture content

It is to simplify that we have considered breakdown factors (temperature and moisture) separately. In fact, they are related to each other and have a closely combined effect. The air-grain equilibrium curves show that the higher the temperature, the lower must be the grain moisture content to assure safe storage. That is why the maximum recommended moisture contents for products stored in hot climates are always lower than those accepted in temperate and cool areas. Figure 5 shows the different deteriorations likely to occur depending on temperature and moisture. It can be observed that grain stored at 25°C and 15 percent moisture content is exposed to attacks by insects, moulds and germination problems (point A) while at 12.5 percent moisture content it is only exposed to attacks by insects (point B). It can finally be noted that grain at 15 percent moisture content is perfectly preserved if it is stored at a temperature of 10°C (point C). The latter case corresponds to storage conditions existing in temperate and cool areas.

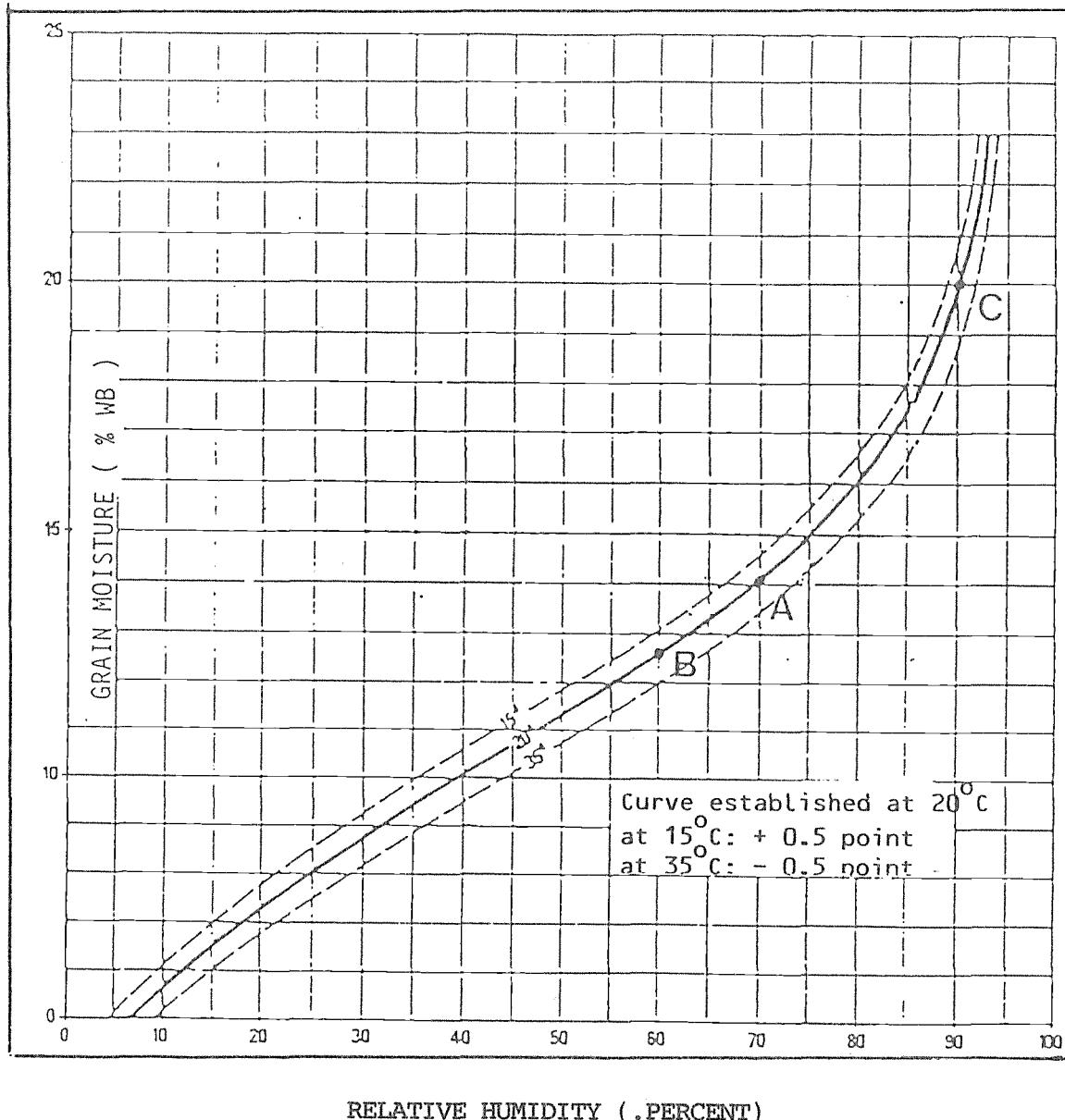


Figure 4: Equilibrium curve for maize at 3 levels of temperature (15°C , 20°C , 35°C)

Comment: It can be noted that at 20°C , grain-maize at 14% moisture content is in equilibrium with air at 70% relative humidity (point A). If ventilation is done with air at 60% RH the grain moisture content will drop to 12.5% (point B). In contrast, if ventilating with air at 90% RH grain will re-humidify up to 20% (point C).

Note: this example has been intentionally simplified to facilitate understanding. In reality, processes are more complex.

Exercise: Q: at 35°C , what is the grain moisture content in equilibrium with air at 60% relative humidity.
A: grain moisture is 12%.

(b) Composition of ambient gases

Insects and moulds are living organisms that need oxygen to grow. If an atmosphere very poor in oxygen is created around grains, insects cannot survive and moulds cease developing. This principle is applied in the so-called methods of controlled atmosphere and neutral atmosphere storage, in which the interstitial air is replaced with inert gas (nitrogen, carbon dioxide or mixture of inert gases). However, the implementation of such methods proves rather difficult (because of the perfectly airtight structures required) and is applied only to bulk storage.

3. Biological agents causing deterioration in stored crops

The main biological agents likely to cause deterioration in stored products in warehouses are microorganisms, insects and rodents. Birds can also cause losses but it is relatively easy to prevent them from entering warehouses.

(a) Microorganisms

Microorganisms, especially moulds, are always present on the grain surface in form of spores. As soon as temperature and moisture are favourable they develop and gradually spread into the stored grain. The lower limits of their development correspond to an air relative humidity of 90 percent for bacteria, 85 percent for yeasts, and 60 to 70 percent for moulds. The range of temperature for their development is very wide: - 8°C to + 80°C. Nevertheless, for each of the species, the range of temperature is reduced and, in most cases, the optimum development occurs between 20 and 40°C.

Climatic conditions in tropical areas, and especially in humid ones, are most favourable to the growth of microorganisms. In dry areas, dangers of attack by moulds also exist when storage conditions are inappropriate. It can be noted that moulds constitute the prime danger for stored crops. There are many species of moulds some of which, such as *Penicillium* and *Aspergillus*, are specific to stored products. Moulds cause a deterioration in the appearance, odour and flavour of the grain where they develop and make it unacceptable for animal and human consumption.

Nevertheless, the major risk generated by the development of moulds on food products is of a sanitary nature: mycoses (diseases caused by fungi) and allergy risks and essentially risks of mycotoxicoses (diseases due to toxins generated by moulds). In effect some moulds can sometimes generate toxic substances. Aflatoxin is the most commonly known; it is a carcinogenic mycotoxin caused by *Aspergillus flavus*. Finally, moulds can alterate and destroy the viability and germination capacity of seeds.

To avoid any risk of moulds it is therefore essential to store only properly dried grain and assess during storage that its moisture content remains lower than the safe moisture content value defined in the preceding chapter. Table 2/2 gives a list of some simple measures to reduce, in some cases, risks of moulds.

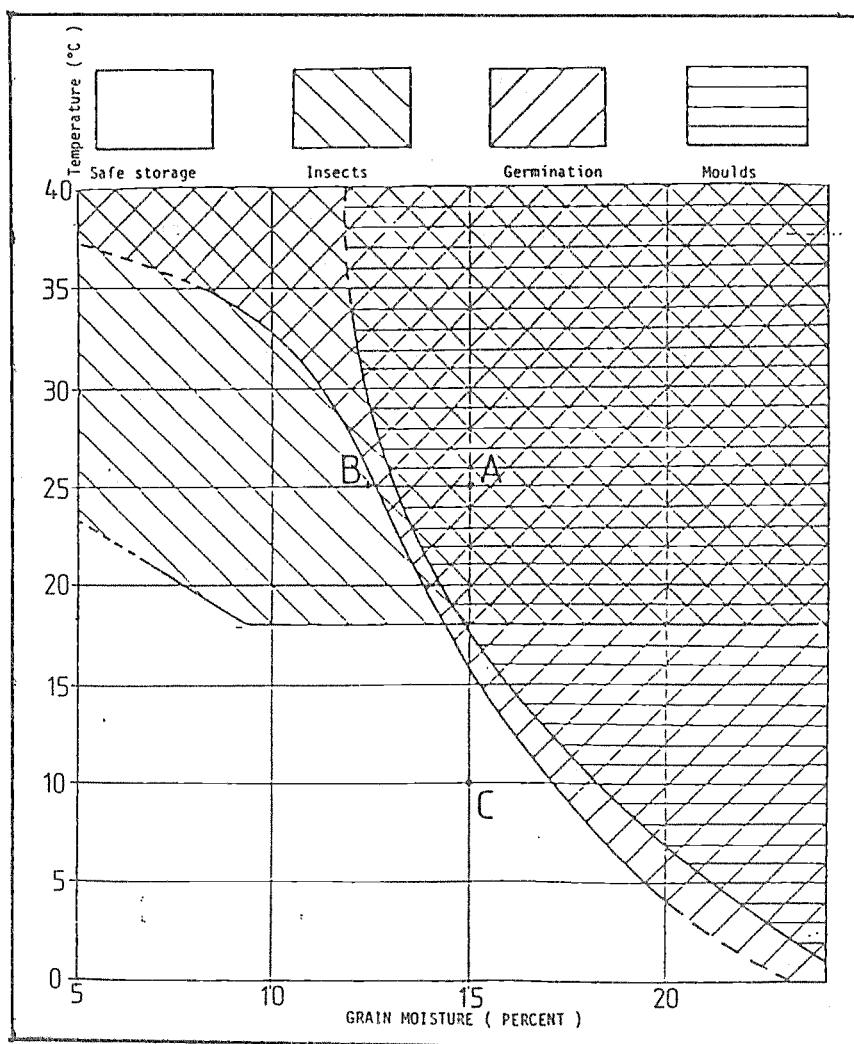


Figure 5: Cereal storage diagramme (from Burgess and Burrel)

Comments:

Points	Characteristics	Possible attacks by
A	Temperature: 25 $^{\circ}\text{C}$ Moisture content: 15%	Insects Moulds, Germination
B	Temperature: 25 $^{\circ}\text{C}$ Moisture content: 12.5%	Insects
C	Temperature: 10 $^{\circ}\text{C}$ Moisture content: 15%	Nil

Exercise: Q: What are the risks of deterioration for grains stored at 14% moisture content and 30 $^{\circ}\text{C}$?
A: Insects, moulds and germination.

(b) Insects

In hot areas, insects cause much damage in stored grain. The prevailing climate in these areas creates conditions favourable to insect multiplication. Most species develop between 15 and 30°C with an optimum at about 25°C-30°C. Low moisture content (11 percent for maize for instance) reduces their multiplication while a high moisture content encourages microorganisms which rapidly compete with insects and kill them.

Insects cause high quantitative losses in stored grains as they eat the endosperm and even sometimes the embryo. For some species living within the grain, it is the larva that causes the highest damage. Depreciation (i.e. loss in market value) of infested grains also results from insect faeces and secretions. Finally their biological activity produces waste (frass), vapour and heat that create conditions favourable to the promotion of mould development.

Many species of insects can attack stored crops. Some of them are specific to stores whilst others can infest growing plants. Finally some species are specific to one plant (e.g. pulse beetles are specific to leguminous plants). Most common insects found in stored grain are described in Annex 3.

Table 2/2. Causes of excessive moisture content and measures to prevent them

Cause of excessive moisture content	Preventive measures
1. Locally produced grains collected at moisture content above safe level	<ul style="list-style-type: none">- Properly dry the grains- Improve drying techniques at farm level
2. Imported grains at moisture content above safe level	<ul style="list-style-type: none">- Properly dry the grains- Apply rigorous quality standards- Inspection and sampling of the stocks before reception (at the port, collection point, at warehouse)
3. Roof leakage and flooding	<ul style="list-style-type: none">- Inspection on a regular basis (roof and surroundings (drainage))- Rapid repairs of any leaking point- Use dunnage
4. Moisture migration from the soil through floor	<ul style="list-style-type: none">- Dunnage- Vapour barrier at floor level
5. Moisture absorption during rainy season or high humidity periods	<ul style="list-style-type: none">- Never allow reception of grain during rain- Control of ventilation openings
6. Wetting during transport	<ul style="list-style-type: none">- Provide trucks transporting grains with watertight plastic sheets

(c) Rodents

Rodents can cause high losses in both growing crops and stored grain. In storage structures they cause direct quantitative losses as they consume the stored product (a granivorous rodent can consume 10 percent of its own weight per day) and qualitative losses as they contaminate the stored product with urine and faeces. Finally, they also cause damage to storage structures and packing; the extent of such damage can vary according to the storage method applied; bag storage is typically more vulnerable than bulk storage.

The main destructive rodents damaging stored crops are as follows: the roof, or black, rat (*Rattus rattus*), the brown, grey or Norway rat (*Rattus norvegicus*) and the mouse (*Mus musculus*). They can be found in practically all climates. Depending on the area concerned, local species of rodent (e.g. the multimammate rat of Africa, *Mastomys*) can also attack stored grain.

From an economic standpoint, the control of rodents is essential because of the losses involved in the field and in stores, and also, from a sanitary standpoint, because rodents can act as vectors of various diseases (rabies, cattle plague and swine fever for example). Such control must mainly be preventive, maintaining rigorous sanitary conditions in both the warehouses and surroundings. Nevertheless, curative methods must be applied when the degree of infestation is very high. Methods of rodent control are described in Chapter 5.

(d) Birds

The large quantities of grain stored in warehouses attract granivorous birds (sparrows, pigeons, etc). They consume grain and contaminate stored products through droppings. Nevertheless it is relatively easy to prevent them from reaching the produce stored in a warehouse by protecting ventilation openings with wire mesh.

4. "Technical" causes of grain deterioration

(a) Length of storage

It is obvious that the longer is the storage period, the higher are the losses in dry matter due to grain respiration. The risks of attack by destructive pests also increase. For a multi-annual storage period it is worth recording that grain must be very dry (see Table 2/1) and stored in a favourable environment (dry and clean) to achieve long-term preservation.

(b) Grain condition

For safe storage, grains must be clean. Foreign matter (dust, flour, straw) and broken grains are particularly exposed to mould and insects and constitute ideal centres of infestation in stored grain.

(c) Condition of the storage structures and packaging

Storage structures of poor design or poorly maintained that allow water, insects and rodents to enter, also damaged packaging (torn bags) encourage attacks of stored grain by the various biological agents of deterioration.

CHAPTER 3

GRAIN QUALITY

A. GENERAL REMARKS

The concept of quality is complex. Quality standards can vary depending on the marketing level or subsequent use of the produce. Grain boards are interested in grain offering good storability and they consequently pay special attention to the moisture content, temperature, foreign matter content and degree of insect and mould infestation. Processing industries are interested in very homogeneous batches of grain with good food, nutritional and milling value. But such differentiation is not so strict since in the countries where grains still constitute the staple food of the human diet, National Grain Boards must also take into account the food and nutritional quality of the produce they put on the market. Finally, regarding seeds, the major interest is for their varietal purity and germination capacity.

Quality standards as defined by the processing industries are rather precise and are frequently referred to as selection standards in the scientific sphere involved in the genetic improvement of crops.

In developing countries where a major part of the food produced is self-consumed, and where such production often proves short in quantity, it is much more difficult to define quality standards and still difficult to ensure compliance with them.

B. QUALITY STANDARDS

1. Grain storability

It is evident that storage is unable to improve intrinsic qualities of grains. Safe storage conditions can only reduce natural deterioration of stored produce. To prevent all risk of deterioration, storekeepers must initially verify that the grain received is free from damage and storable, by checking certain characteristics.

(a) Grain moisture content

It is essential to know this with accuracy if successful grain storage is to be expected. Some empirical methods that refer to grain hardness, the sound it makes when shaken in a tin, its odour or flowability are still applied sometimes. They only allow to form an opinion and must systematically be excluded in storage centres because they are highly subjective and can be very dangerous. In effect, as shown in the preceding chapter, grain stability regarding attack by microorganisms can be obtained only for very precise moisture contents which can only be measured by scientific methods.

The various devices for determining moisture content can measure physical properties closely related to the grain moisture content. Table 3/1 below indicates for each case, the device employed.

Table 3/1. Moisture content measurement

Property measured	Device used	Measurement
Weight loss due to complete drying	Drying oven	Good
Grain conductivity and dielectric constant	Electrical moisture meters	Less good
Relative humidity of air in equilibrium with grain	Hair hygrometer	Doubtful

In spite of the defects these devices may still present, their use must be extended in all storage and collecting centres. The various methods of determining moisture content are described in Annex 2.

(b) Specific weight

The specific weight is measured for some cereals. This corresponds to the weight of 100 l of grain. This measure allows an overall evaluation of the grain moisture content, cleanliness and maturity. This is a measurement frequently applied to wheat.

(c) Foreign matter

The term covers a wide variety of elements that are as follows:

i. Inert materials including:

- mineral materials such as gravel, sand, clay, mud;
- animal elements such as insects, animal residues, hairs, larvae;
- vegetable wastes such as straw, leaves, stalk and cobs;
- others such as metal fragments, rodent droppings, string;

ii. Seeds from other cereals or other families of plants.

iii. Grains from the cereal or pulse concerned, with one of the following damages:

- broken grain;
- spoiled or mouldy grain;
- discoloured grain (e.g. overheated grain);
- pest-damaged grain;
- germinated grain;
- immature grain.

All these elements will impede safe storage of unblemished grain. Broken or/and damaged grains, immature ones, vegetable wastes and dust are typically more moist than unblemished grains and as such they constitute ideal places for insect and mould attacks; mouldy grain should be removed. It may be a temptation to dispose of mouldy grain by mixing it with unblemished one into a same batch; this is bad practice as it will multiply infestation centres and can result in damaging the whole batch. The presence of foreign matter also distorts measurements of moisture content and specific weights.

The foreign matter content is determined from small samples (e.g. 200g for maize). Visual sorting and sieving allow foreign matter to be separated from sound grain; it is then classified and respectively weighed to obtain the foreign matter content. According to the country concerned, quality standards referring to the commodities stored are more or less severe; they give the limits above which prices are rebated.

Example: maize (in France)

Foreign matter	Limit (in percent)
Broken grains	4
Damaged grain	4
Germinated grain	2.5
Miscellaneous	1

paddy rice (in India)

Foreign matter	Limit (in percent)
Miscellaneous	1
Damaged grain	5
Broken grain	2
Insect-damaged grain	1
Immature grain	2
Discoloured grain	2

Sound grain of perfect quality must generally constitute 90 percent of the sample.

2. Quality standards according to the use of grain

Such standards are mainly used after the storage stage, e.g. at the processing and consumption level. They can nevertheless indicate whether the storage conditions were safe. They concern food, nutritional and processing qualities of grain.

(a) Food quality

- absence of toxins
- absence of pesticide residue
- organoleptic characteristics unchanged (flavour, odour, colour)

As the process for determining mycotoxin and residue percentage is complex it can only be carried out in specialized laboratories.

(b) Nutritional quality

- biochemical analysis to determine nutritional elements
- growth tests on animals
- tasting tests

(c) Processing quality

Standards vary according to the commodity involved; so, whilst the starch value will be considered for maize, it will be the milling yield (including head/broken grain ratio) and cooking value for rice, etc.

Processing industries are looking for products of constant and standard quality, and also as homogeneous as possible.

In any case, as it is impossible to know the characteristics of a whole mass of grain, the analysis must be conducted on samples that must essentially be representative.

C. SAMPLING OF PRODUCTS

The sampling process consists of various operations that, from a mass of produce, allows one to obtain a small quantity (or sample) as representative as possible, that will be used for analyses to determine certain characteristics.

1. Sampling methods

Primary samples are taken and mixed so as to obtain a bulk sample. The less uniform the batch of produce, the higher must be the number of primary samples taken to obtain a bulk sample as representative as possible of the whole batch.

(a) Number of primary samples

This depends on the number of bags delivered.

- | | |
|--------------------|---|
| 1 - 10 bags | : every bag must be sampled |
| 10 - 100 bags | : 10, drawn at random |
| more than 100 bags | : the number of primary samples must be equal or immediately above the square root of the total number of bags. |

When one or several bags delivered offer a very bad appearance, quite different from the general appearance of the consignment, they must be removed and separately considered.

(b) Sampling methods

In bag storage, sampling cannot be mechanized. Therefore sampling can be made by emptying the bags or, more commonly by using sampling spears.

Bag emptying

Bags taken at random are individually emptied onto a concrete area or a perfectly clean tarpaulin. The content of each bag is thoroughly mixed then spread out in a thin layer less than 10 cm deep; 1 kg of the grain is taken at random from every batch. The various samples that so constitute a primary sample are then well mixed. Analyses and assessments can be made on a reduced portion of this primary sample. Such method is of interest because it allows a rapid visual examination of the quality of the grain delivered. Nevertheless, as it may seem rather slow and tedious the spear sampling method is often preferred.

Bag sampling with spears

This method offers the advantage of being more rapid and not requiring the opening of bags. Samples are taken at random from different places in the bags selected. If 10 bags must be sampled (10 from 100 bags delivered), at least 50gr of product must be taken per bag of 100kg. If more than 10 bags must be sampled (consignment over 100 bags) the quantity taken per bag can be less than 50gr per bag of 100kg. The total sample taken must never be less than 500gr if a representative working sample of sufficient quantity for analyses is to be obtained.

Samples are taken using hollow metal spears called bag samplers (Figure 6). Their disadvantage is that they will leave holes in the bag wall, which can constitute subsequent sources of spillage.

A double tube sampling spear (Figure 7) can also be used but bags must be open.

2. Subsampling

The bulk sample obtained by mixing primary samples can often be quite large. This must often be reduced to obtain more workable amounts of grain for analyses.

There are several methods of reducing sample size and obtaining representative subsamples.

(a) The coning method

The bulk sample is first piled up then thoroughly mixed, coned and divided into 2 or 4 equal parts, each of them constituting a sub-sample. The process can be so repeated until the subsample size desired. Figure 8 illustrates the reduction by half of a sample using the coning method. This method is very simple and does not require any special instrumentation but only a very clean area of a reasonable size for implementing it. Nevertheless some errors may occur.

(b) Boerner divider

As shown in Figure 9, the divider is composed of a cone into which is poured the sample to be divided. At the base of the cone, grains are trapped by vents grouped in two outlet chutes beneath the divider.

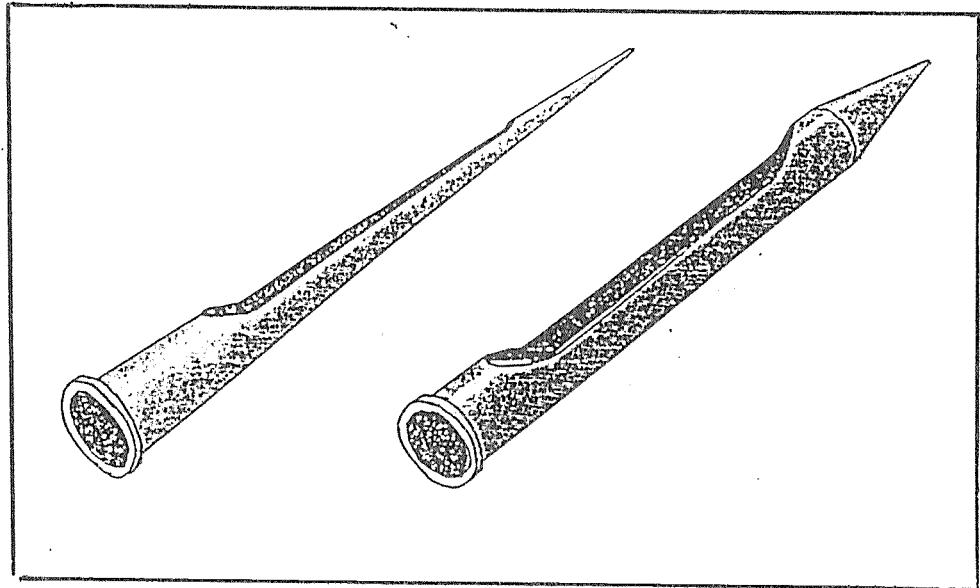


Figure 6: Sampling spears Sm des

Chigae

1 - Tapered.

2 - Cylindrical.

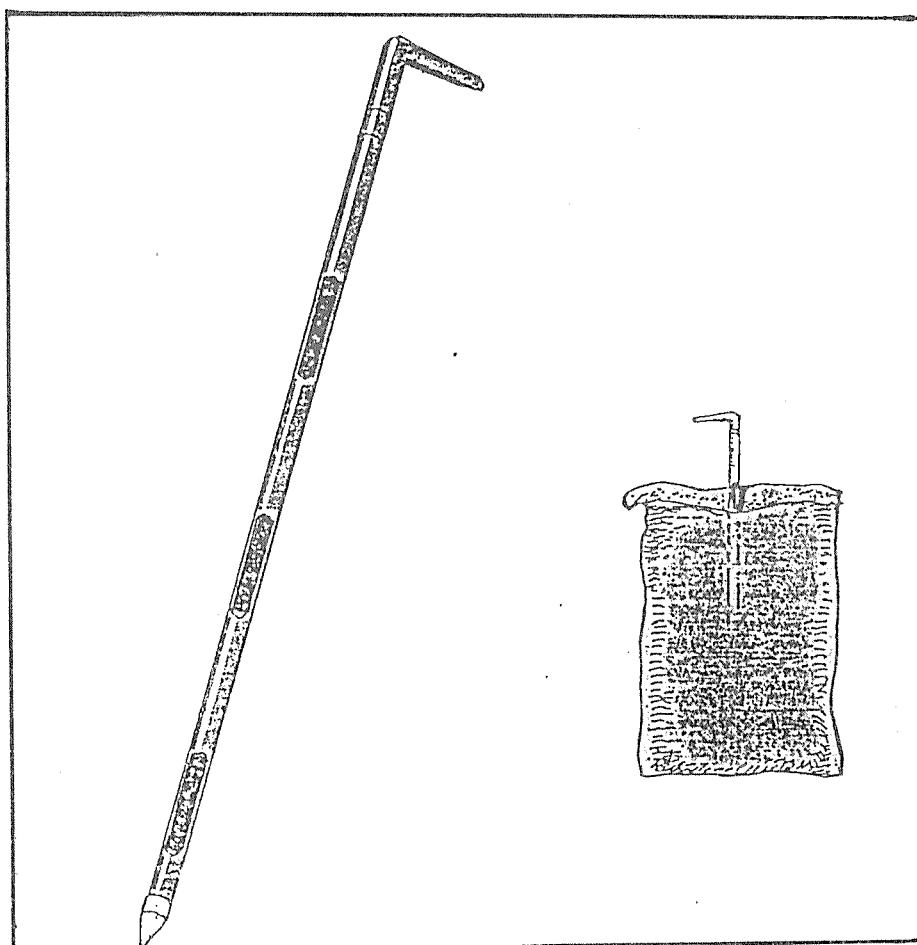


Figure 7: A 3-compartment sampling spear

Can - smde à 3 compartments

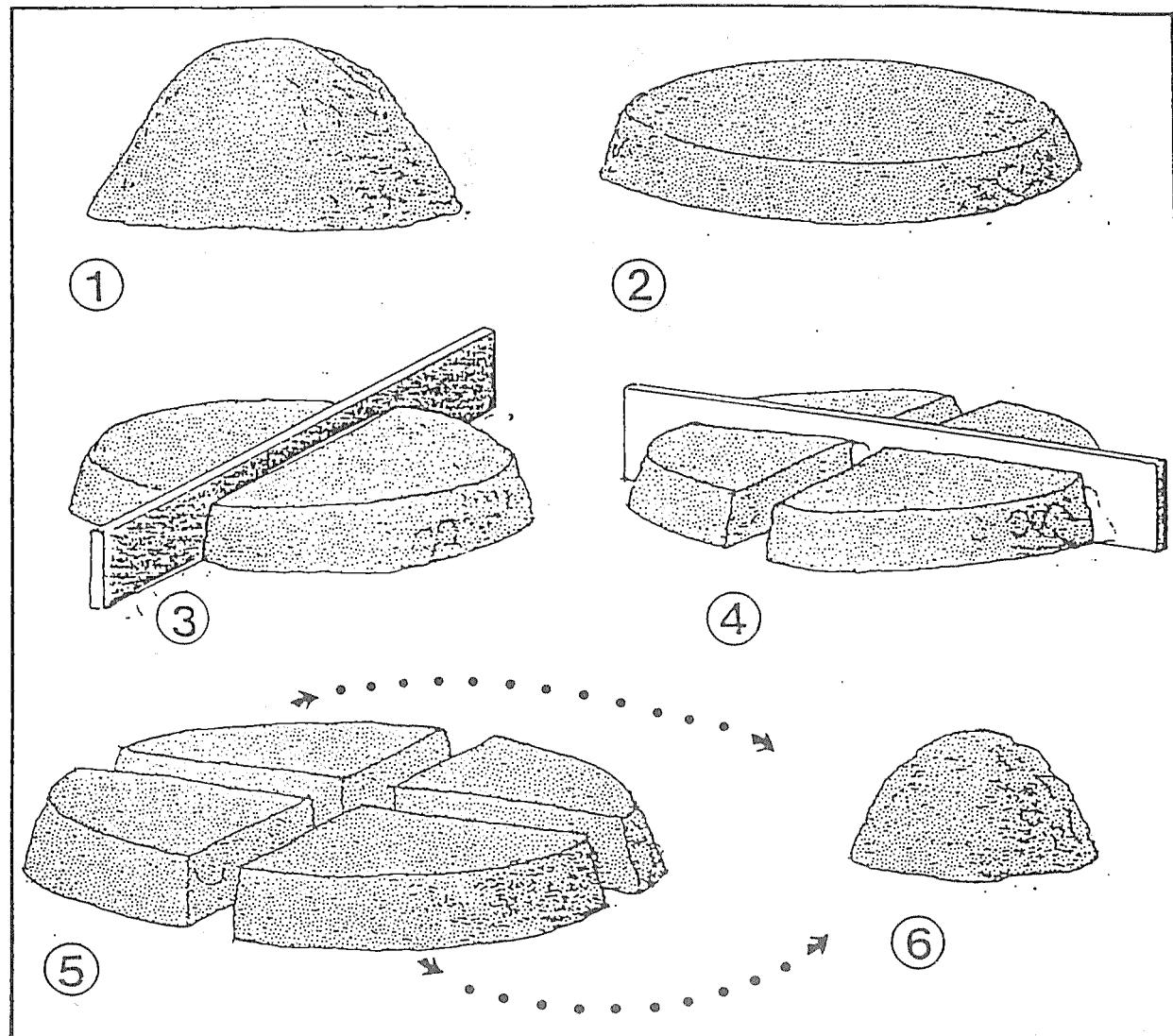


Figure 8: The coning method applied to divide a sample

1. Bulk sample to be reduced: grains thoroughly mixed then coned.
2. The cone has been flattened.
3. The cone is being divided into two equal portions, using a small board.
4. The sample is further divided resulting in four equal portions.
5. Two opposite quarters are being put together and mixed to constitute a representative subsample (6).

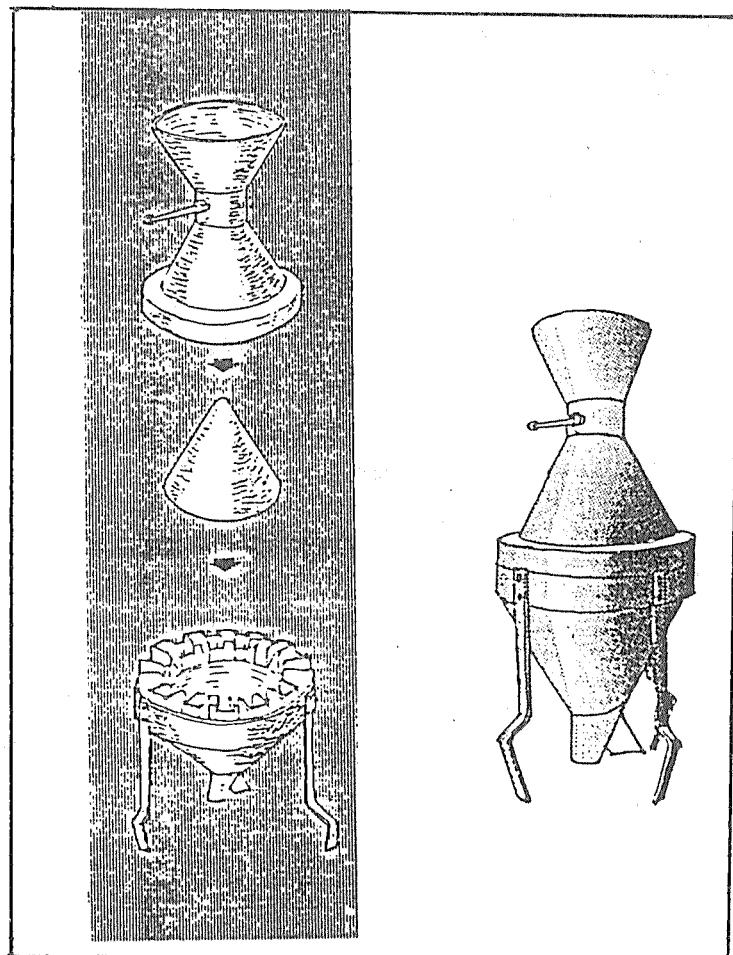


Figure 9: Components of a Boerner divider

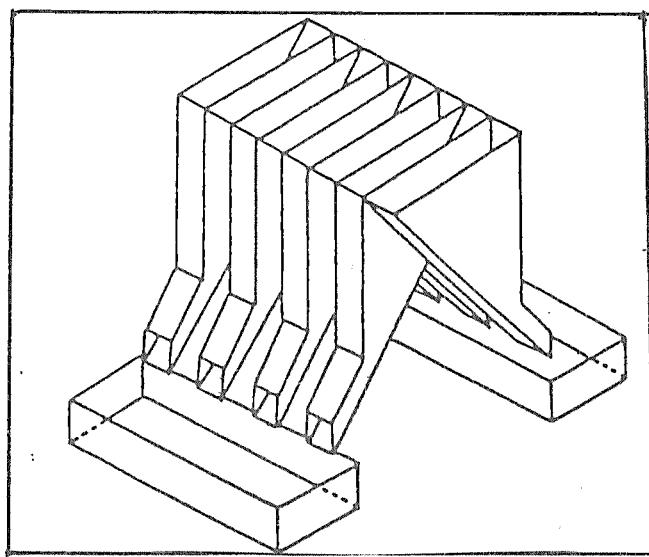


Figure 10: Riffle divider

Such equipment allows a sample to be divided into two equal halves; nevertheless there must not be too much vegetable waste which can choke some of the vents; it is relatively expensive equipment.

Other instruments of the same type but of a larger size allow the contents of a whole bag to be divided.

(c) Riffle divider

Such equipment consists of several compartments allowing the sample to be divided into two equal portions as shown in Figure 10. It is largely used for seed sampling because all the parts of the instrument are visible and easily accessible.

D. EQUIPMENT REQUIRED FOR SAMPLE ANALYSIS

For the common analyses that can be made at store level, the following equipment is needed:

(a) Basic facilities and equipment

- A well-illuminated place for analyses separate or not from the storekeeper's office depending on the store size.
- A work table with a raised edge and a smooth top perfectly clean and easily maintained.
- Spears and grain scoops for taking samples and to mix the grain.
- Balance(s).
- Moisture meter(s).
- A set of laboratory sieves specific to the commodities involved.
- Other small equipment such as pans, bowls, small containers and vessels, brushes, tweezers, (small bags) scalpels.

(b) Optional equipment

- Sample divider.
- Hectoliter or liter tester for measuring specific weight.
- Magnifying glass.
- Pocket calculator.

CHAPTER 4

BAG STORAGE

A. GENERAL REMARKS

Although grain storage in bags has almost totally disappeared in industrialized countries this method is still widely applied in developing countries; it proves well-adapted to those countries where commodities are mainly delivered in bags to the market. Regarding storage structures, the capital investment required for bag storage is lower than for bulk storage and existing buildings can be used. Nevertheless bag storage structures must not be simple shelters; they must also satisfy some parameters the purpose of which is to protect stored grain against deterioration; these parameters are as follows:

- prevent water and moisture from entering the warehouse
- protect the stored produce against high temperatures
- prevent pests (mainly insects and rodents) from entering the warehouses.

There are two major types of bag storage. On the one hand, storage in warehouses or stores, which constitutes the more common method, and on the other, storage in flexible silos mainly applied for food security stocks or to temporarily mitigate low capacity in existing warehouses.

B. SUITABILITY OF STRUCTURES FOR GRAIN STORAGE

Two aspects must be considered: the design of new warehouses on the one hand and on the other, the conversion of existing buildings into warehouses.

1. Design of warehouses for bag storage of grain

(a) Layout and orientation of a warehouse

The site chosen for building a warehouse must be at a safe distance from dwellings, along an all-weather thoroughfare (e.g. a main road) and near water and electric networks but, if possible not close to standing water (lakes) nor running ones (rivers, streams). The site topography must also be taken into consideration so as to avoid easily flooded and low lands, clayey and poorly-drained soils; high sites (hillocks, hills) from which rainwater can easily drain are preferred. In any case Rural Engineering Services must be consulted and the information so gathered must be confirmed by interviewing the populations living near the site chosen (e.g. regarding flooding risks).

To reduce high temperature rises in the warehouse, the wall surfaces exposed to sunlight must be as small as possible. In warm regions where the strongest solar radiation corresponds to east and west, buildings must be oriented about an east-west axis so that the smallest wall surfaces (i.e. end walls) are exposed to intense solar radiation.

(b) Design and dimensions of a warehouse

The dimensions will depend on the quantity of produce to be stored in the warehouse and also on the following parameters

- specific volume of the commodities to be stored in bags;
- height of bag-stacks (related to the nature of the bags used);
- separation into several batches according to the commodities concerned;
- width of alleys for handling and control purposes;
- number and size of annex premises and facilities (working space, office, laboratory, implement shed).

To allow good conditions of management, stores are commonly in a rectangular shape with their length approximately twice their width.

Table 4/1. Specific volume of products stored in bags

Produce	Specific volume (m ³ /tonne)
- Beans, peas, lentils	1.3
- Milled rice, wheat	1.6
- Maize, sorghum, shelled groundnut, coffee	1.8
- Maize flour, wheat	2.1

Height of bag-stacks

For plastic bags (polypropylene bags) that are prone to slip stack height must be reduced (3m as a maximum) whereas with jute bags height can be greater (up to 5-6m). In any case a free space must be provided above the stacks for control purposes.

Separation of produce into several batches

For a given volume, the maximum capacity of storage is obtained by storing the produce in one stack. Nevertheless, due to management and control problems and also to the different nature of the crops to be stored, generally this solution cannot be applied, except sometimes in very small stores. In any case, stacks must be separated and alleys

must be provided 1m wide between walls and stacks for inspection, and 2-3m wide for handling. The total area of these alleys must be included when calculating a warehouse size.

A practical example for calculating a warehouse size is given in Annex 4.

For small warehouses (up to 200 m² of floor area) the volume effectively used generally corresponds to 30-70 percent of the available volume, according to the stacking chosen. Such value is obviously higher for large warehouses in which it can range from 50 to 80 p.c.

Annex premises and facilities

In practice a store consisting only of four walls and a roof cannot constitute a functional structure. While such buildings should be exclusively devoted to grain storage, they frequently include the storekeeper's office and the various cleaning, handling and other equipment; this means that the storekeeper cannot achieve, or only with difficulty, good safe management of the stored crop. At the design level, it is therefore necessary to envisage that annex premises and facilities will be separate from the sorting structure and will include:

- a covered working space for grain reception, assessment and possible reconditioning;
- an office laboratory for the storekeeper; it can consist of two separate rooms, at large warehouses;
- a shed for equipment and chemicals (weighing machines, sprayers, brooms, insecticide chemicals, etc.).

Figures 11 and 12 show two possible types of buildings for small centres (collecting, distribution centres).

(c) Construction of warehouses

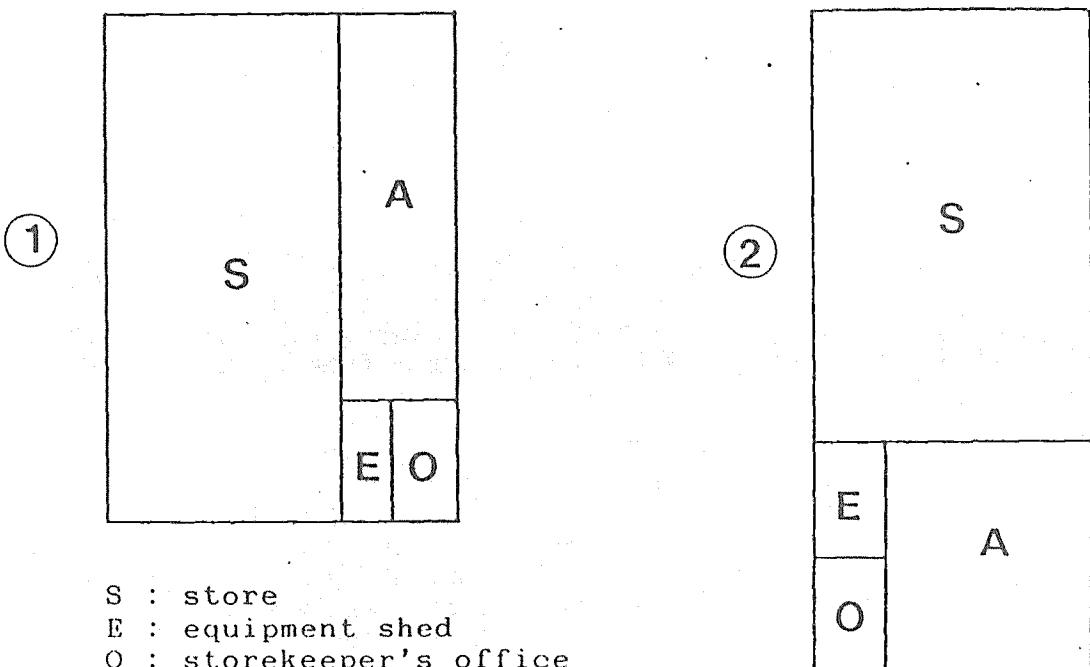
Only brief information on the main points regarding the construction of warehouses is given here. For further information, the reader can usefully consult the document "Standardized design for grain stores in hot dry climates" FAO Agricultural Services Bulletin No.62".

Foundations

Unstable clayey soils and backfilled areas of poor bearing capacity must be avoided as they can result in settling that will cause cracks in structures. In any case the topsoil should be removed until a soil layer resisting pressure above 150 kN/m² is reached.

Warehouse floor

The floor must be correctly designed and constructed so as to resist pressure from bag-stacks and prevent damp rising from the soil. It generally consists of reinforced concrete slabs placed over a well-compacted base layer. A damp-proof layer made of a polythene



- 1- Covered area on side wall (verandah)
- 2- Covered area on end wall (see Figure 15)

Figure 11: Standard sketch plan of storage warehouses

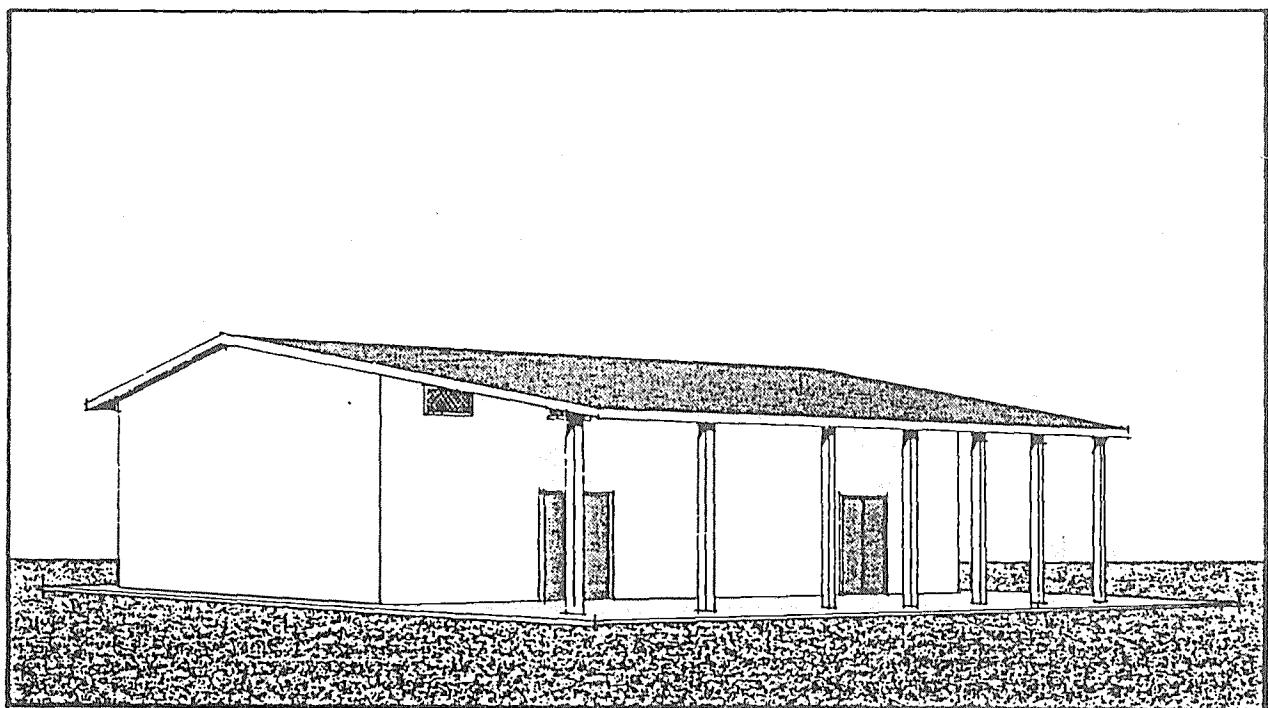


Figure 12: Small store with verandah

sheet, bitumen or bituminous felt is placed between both surfaces to prevent capillary movement of water to the underside of the floor. The concrete slab must be provided with expansion joints to prevent cracks that always prove difficult to control as far as the store hygiene is concerned. Finally, a floor finish is applied which consists of a smooth cement coat, also surface treated to prevent dust formation.

The store slab must be laid after constructing the roof that will protect it from direct solar radiation and prevent concrete from setting too quickly. The option that consists of planning a suspended concrete floor above compacted backfilling will generally result in extra cost (rarely justified).

In certain areas, it may be necessary to treat the soil against termites.

Building structure and walls

The building structure consists of columns supporting the roof trusses and beams connecting columns together. The frame is commonly of reinforced concrete; it can also be of steel beams. Columns inside the store must be avoided as they will result in problems of the store management. Walls can be of the load-bearing or non-load-bearing type. Non-load-bearing walls made of aluminium, galvanized sheet iron or asbestos cement sheets offer the advantage of being rapidly installed; their major disadvantage is that they are not very strong and have a low thermal inertia; some of them also offer risks of corrosion. Bricks and concrete blocks are therefore generally preferred for load-bearing walls as they provide a better strength to the building and also, due to their thermal inertia, reduce the effects of diurnal variations in temperature. All around the store, a splash apron about 1m wide must be laid so that the bottom of the wall should not be washed away by the rainwater from the roof.

Roof

The roof frame generally consists of metal riveted, bolted or welded elements; timber works can also be used. Metal frames allow for truss spacings 7 to 8m wide, while for timber trusses, spacing must not be over 5m. The wood employed must be properly dry and treated. Metal frames prove easier to maintain and control (hygiene) than timber ones.

Roof covering can be made of asbestos-cement sheets, galvanized steel sheets or aluminium. Thermal inertia of asbestos-cement sheets is higher than that of metal sheets, but as they are fragile, they require careful handling and installation. The roof overhang must be 0.70 to 1m on end walls and at least 1m on side walls to efficiently protect ventilation openings from rain.

Opening.

Doors: the number will vary depending on the store size; nevertheless, at least two doors are necessary to facilitate store management. When located on the same wall in the store, they allow

better control of stock inlet and outlet. Preferably metallic, doors must be of adequate size (minimum 2.5m wide, 2.5m high) and close tightly. From this standpoint, double-hinged doors are clearly more convenient than sliding ones that leave space between the door and the wall, letting in rodents and insects. Hinged doors should open outwards so that they do not reduce the storage space available within the store. A canopy, as shown in Figure 13 will protect doors from rain.

Ventilation openings: they are necessary to allow the airing of the store and to reduce temperatures as well; they also provide light. Their location in the lower part of the wall must be avoided as this will result in many problems such as entry of rain water and rodents; they must therefore be located at the top of the side walls, beneath the roof overhang so that they are protected from rain. Such openings, of adequate size (e.g. 40cm x 80cm) must be screened with wire mesh outside, to keep out the birds, and mosquito netting inside. As shown in Figure 14, they can also be protected by an external top-hinged shutter. Small ventilation openings should also be allowed at the top of both end walls for letting out the hot air accumulated under the roof.

Some of the points mentioned above are illustrated in Figures 15 and 16. The external view shows a working space designed on the end wall; the space also shelters annex premises (office and equipment shed). On the inside view, perfectly smooth walls and top openings protected from predators can be noted.

2. Use of existing buildings

As compared with bulk storage, one of the few advantages of bag storage is that it makes possible the use of existing buildings. Nevertheless, as all buildings are not perfectly suited for grain storage, before considering a building as such, it must be thoroughly inspected and critically discussed.

(a) Preliminary survey

The various points that must be inspected are as follows:

- i. Survey of the site.
- ii. Inspection of the building (size, materials used, condition).
 - roof (frame and covering)
 - floor
 - walls
 - openings (doors and ventilation)
 - available space.

All these points should be analysed according to requirements already listed i.e.:

- prevent water from entering the store;
- stored crops should be protected against high temperature;
- stored crops should be protected from insect and rodent attack;
- easy control and management of the store must be assured.

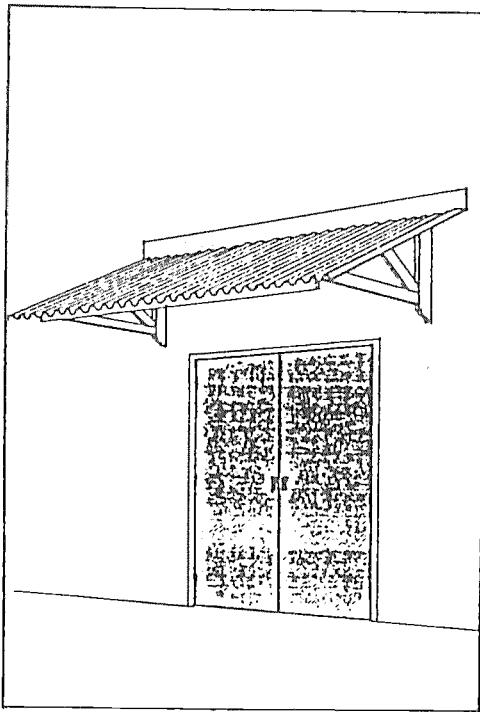


Figure 13: Canopy to protect doors from rain

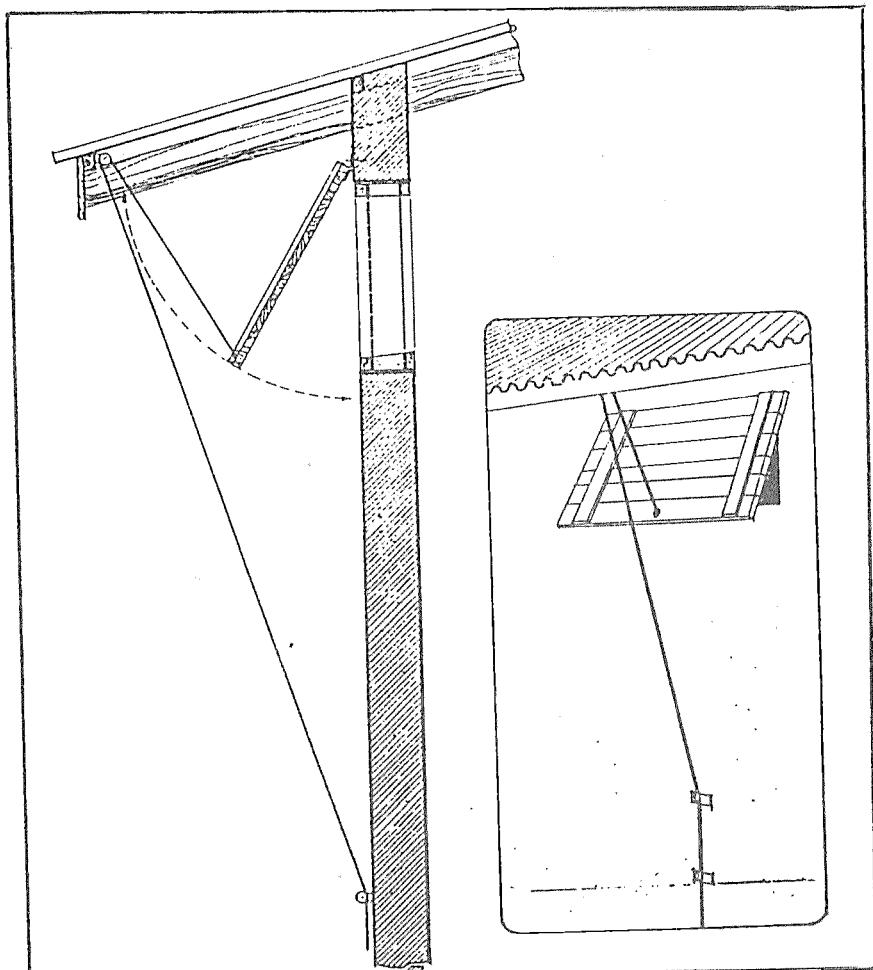


Figure 14: Eaves ventilation with wooden shutter

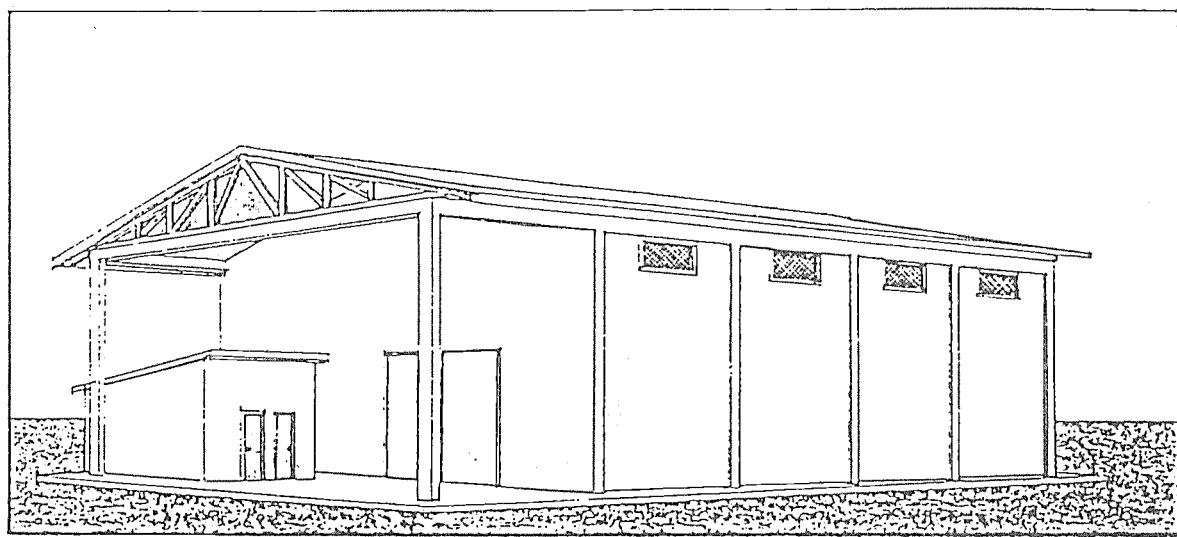


Figure 15: Warehouse with a working area on end wall

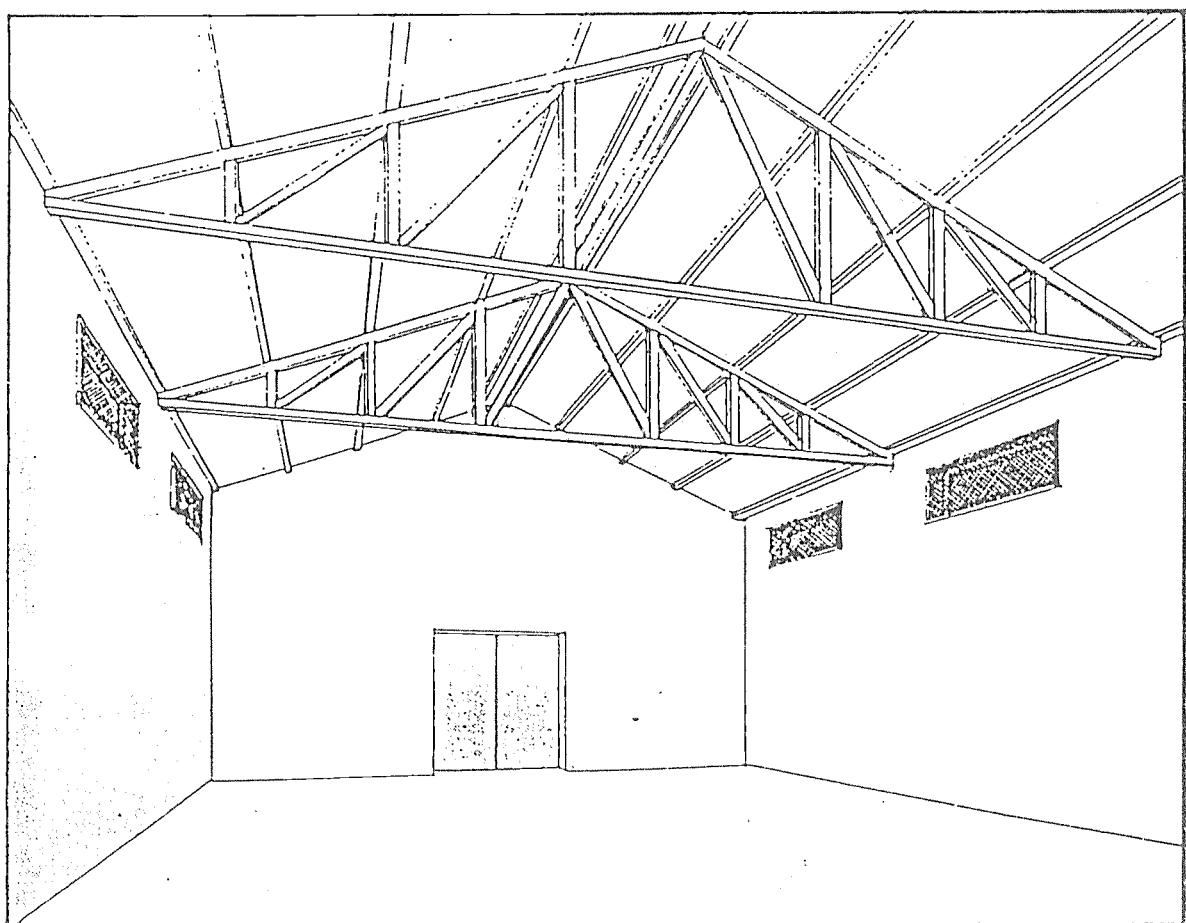


Figure 16: Inside view of a warehouse

A cost estimate should then be made of all the required repairs and modifications. A decision on whether a building can be used or not for grain storage should be made only after the technical survey and economic analysis are completed.

(b) Technical considerations on existing buildings

Concerning the technical consideration to be taken into account when choosing whether the building is suitable or not, the reader will usefully refer to the preceding chapter where design parameters regarding warehouses for bag-storage of grain are listed.

Site selection: any building located in an easily flooded area should systematically be considered as unsuited to grain storage. When such risk does not appear, the inspection of the building should determine whether it is possible to protect it efficiently from run-off water (rain) through drains.

Building

The roof must be perfectly watertight. An inspection from inside for "daylight" will reveal cracks and/or holes in the roofs. An inspection carried out on a rainy day will reveal leaks. All defective metal or asbestos-cement sheet should be replaced. In a building provided with a ceiling this may be removed as it can mask leaks and harbour rodents. Down pipes must be cleaned out and provided with rodent-proof protection.

The floor should preferably be of properly jointed and level concrete slabs. Cracks, that can fill with loose grain, will constitute centres of infestation for the stored produce and should therefore be cemented. The floor should be perfectly watertight and prevent water from penetrating by capillary action. A simple method can be applied to assess the floor water-tightness: if a plastic sheet is fixed on the floor with adhesive tapes, if some time later water droplets appear under the plastic sheet this means that the floor is not watertight. In such a case, the top screed should be removed, a vapour barrier (plastic or bitumen sheet) placed on the old concrete and a new reinforced concrete slab laid above, as shown in Figure 17.

Walls: if walls are of metal or asbesto-cement sheets, all the defective elements must be replaced; another solution consists in replacing walls of light materials with walls of concrete blocks on the whole height, or at least up to 1.5m above the floor, to facilitate rodent control and keep water from penetrating.

If the walls are built of concrete blocks or bricks, the quality of rendering should be checked. All crevices and cracks should be cemented. Major cracks may make it necessary to replace the defective blocks concerned. If there is a gap between the walls and the roofing sheets it must be filled with concrete. Figure 18 illustrates the jointing required between the walls and the roofing. A light-coloured coating (paint or whitewash) should be applied on both faces of the walls.

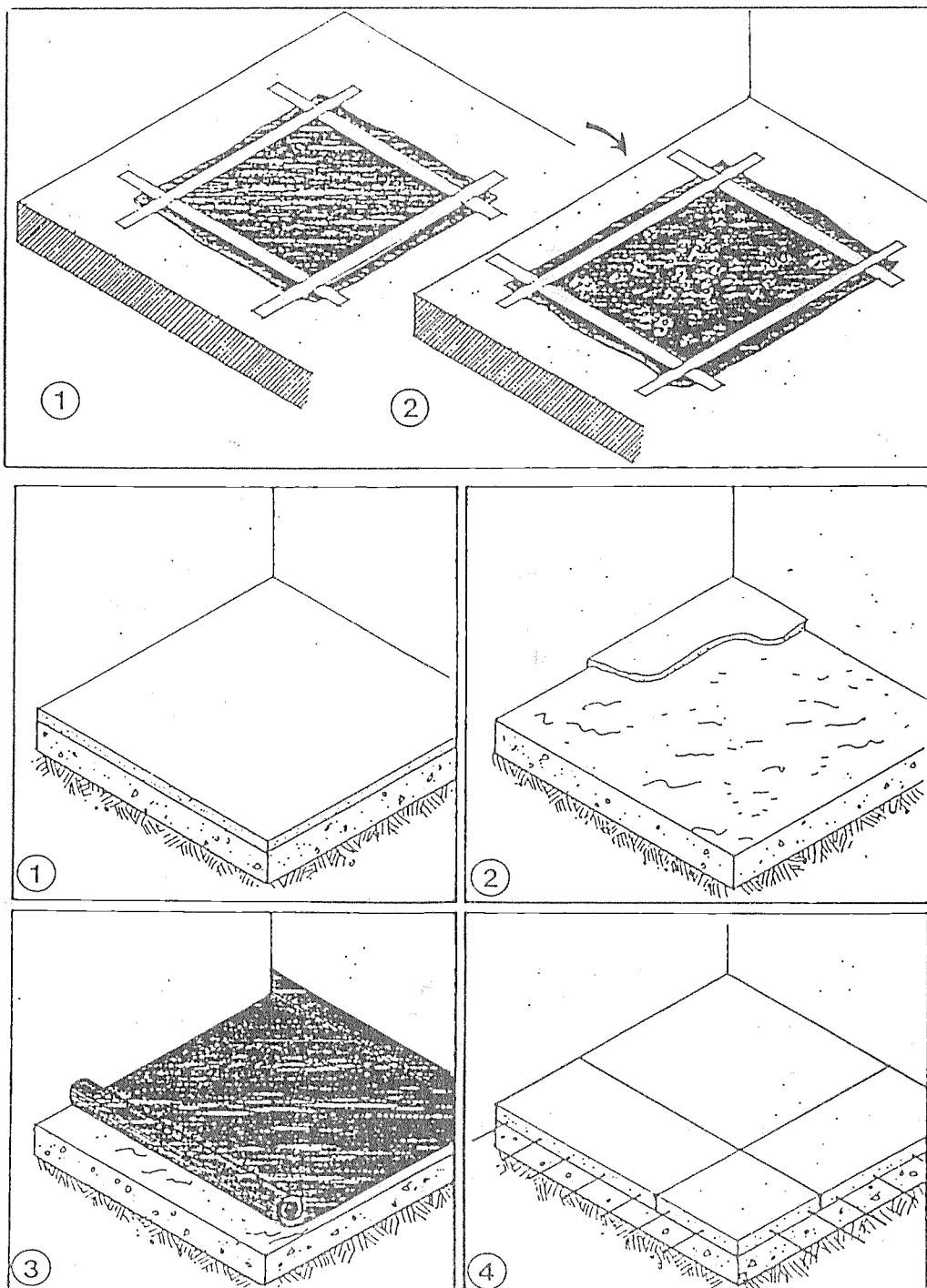


Figure 17: Repairing a non-watertight floor

- A: (1-2 – Verification of watertightness)
B: 1. Non-watertight floor. 2. Top screed removal.
3. Laying of damp-proof course. 4. New reinforced floor.

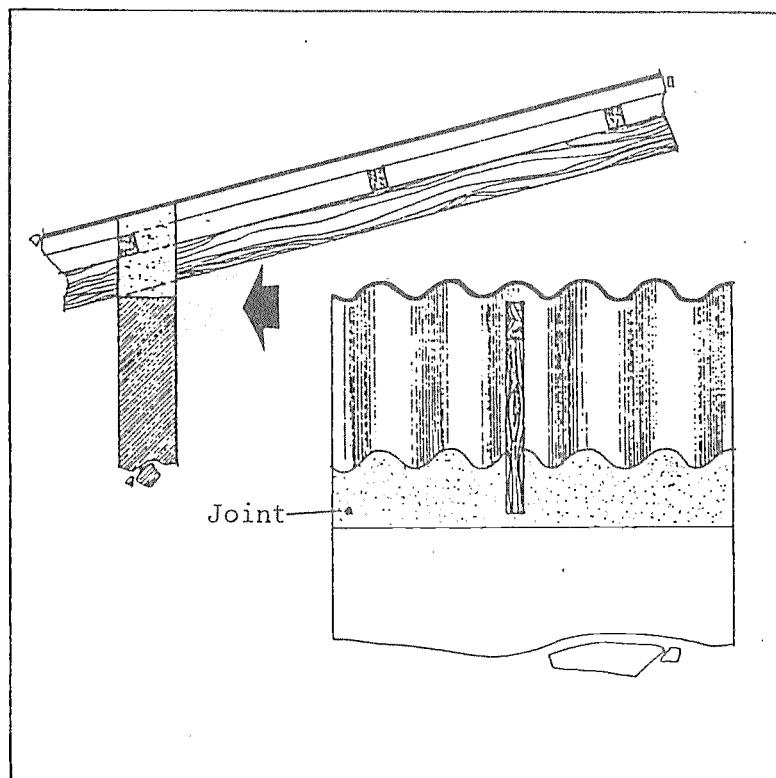


Figure 18: Jointing between walls and roof

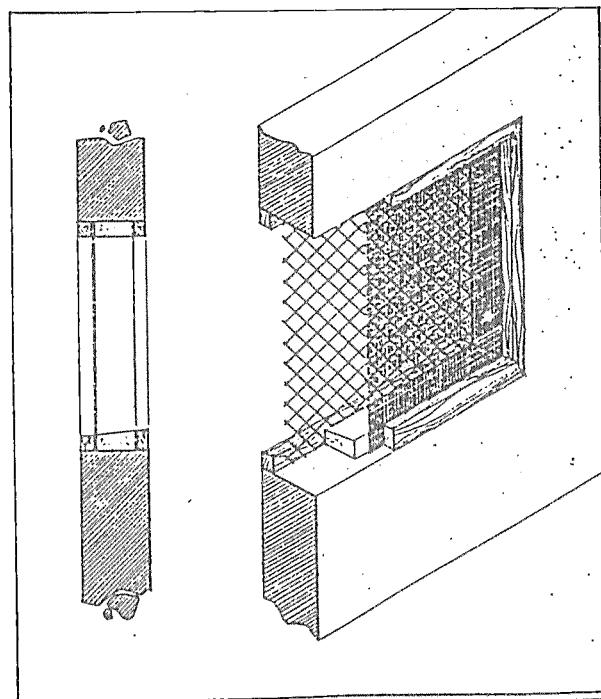
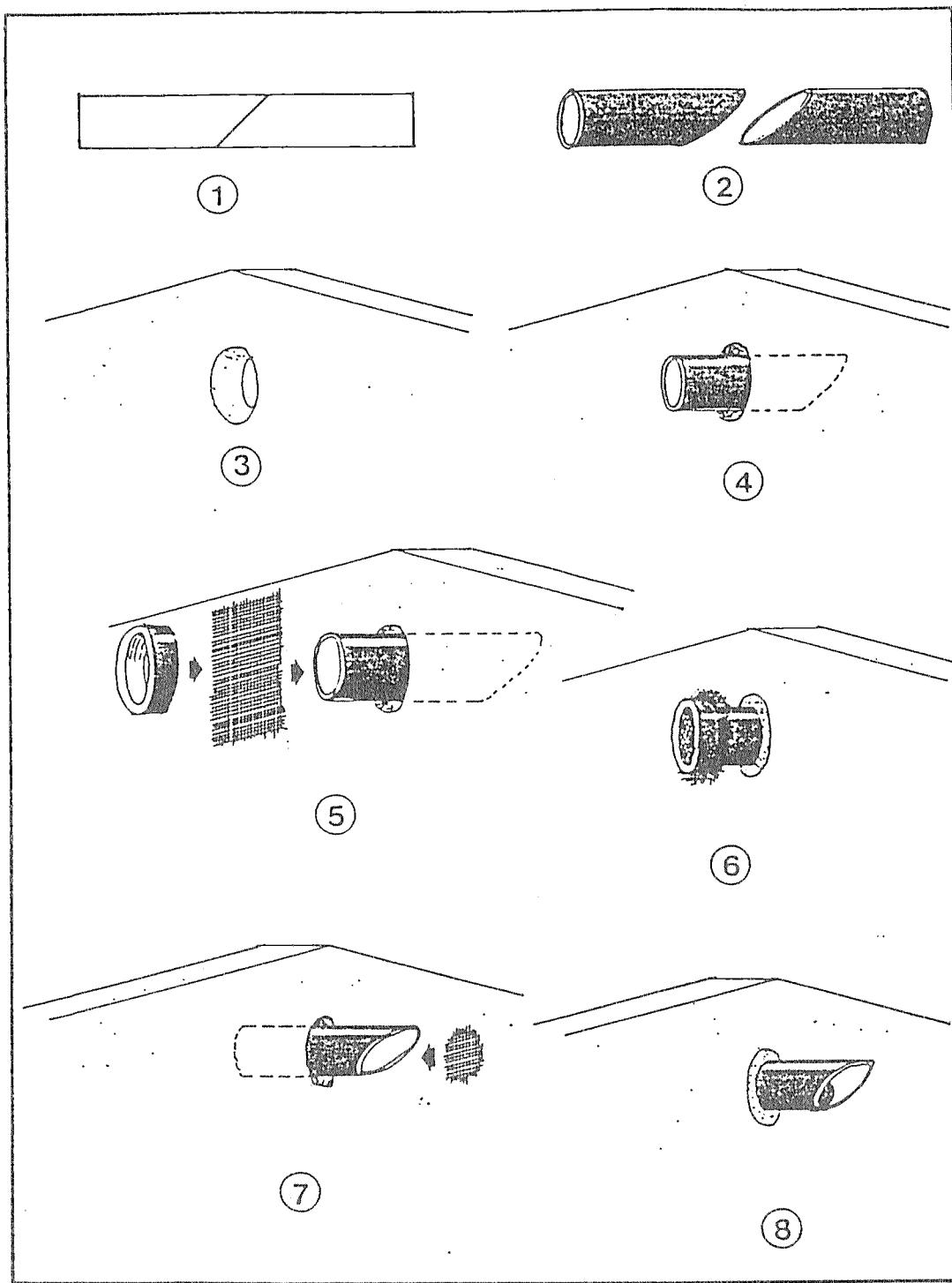


Figure 19: Eaves ventilation provided with a wire-mesh and an insect screen



- 1-2. Two short pipes for each end wall.
- 3-4. Opening in the wall to put the pipe.
- 5-6. Placing of insect screen (inside view).
- 7-8. Outside end of the pipe provided with wire-mesh.

Figure 20: Aeration at the top of an end wall

Ventilation openings: all the openings located in the lower part of the walls must be properly closed and upper ones enlarged if necessary. These should be located at the top of the walls (under the eaves) so as to be properly protected from rain. They should be provided with a wire mesh on the outside face and on the inside one with mosquito netting, fixed on a removable frame spaced at least 10cm from the wire-mesh as shown in Figure 19. These openings may also be equipped with a top-hinged shutter, of metal or wood (see Figure 14). At the top of both end walls there must be an opening properly protected from rain, birds and insects; if not, such openings should be provided. One method consists in placing a short metal or asbestos-cement pipe through the end wall; the outside end of the pipe is bevelled and provided with wire-mesh, the inside one is protected with mosquito netting fixed by a steel coupling flange. Figure 20 illustrates the installation of openings in the upper part of end walls.

Doors: stores must preferably be provided with metal double hinged doors. When sliding doors already exist that cannot be replaced, they must be made rodent-proof. A simple method is to provide the door and stiles with small metal sheets (over 1m high) that will be in close contact when the door is shut, as shown in Figure 21.

If wooden doors are used, the lower part should be covered with metal sheet to prevent rodent attack. (Figure 22)

Doors should be protected from rain by a canopy (Figure 13).

Inside of the buildings

In existing buildings the inside space may sometimes be divided into several rooms by partitions. As far as grain storage is concerned, such an arrangement would interfere with storage handling and management. During the survey inspection, each partition should be thoroughly examined; all the partitions that neither constitute load-bearing walls nor contribute to building stability should be removed so as to open maximum free space within the warehouse.

3. Maintenance of buildings

Maintenance operations should be carried out on a regular basis to provide good storage conditions and also to increase the life of buildings. These operations will consist of small regular repairs within the storekeeper's capability, or of major works that should be planned and carried out during the off-season and must often be done by skilled craftsmen.

(a) Small repairs

i. Roof inspection and repair

Weather can cause damage in roofing sheets (such as displaced sheets, drawn nails, cracked asbestos sheets). It is therefore necessary to periodically check roof conditions and, if required, replace nails, fill up gaps and/or cracks with bitumen, "flashband" or mastic. However, if the damage is severe, the whole defective sheet

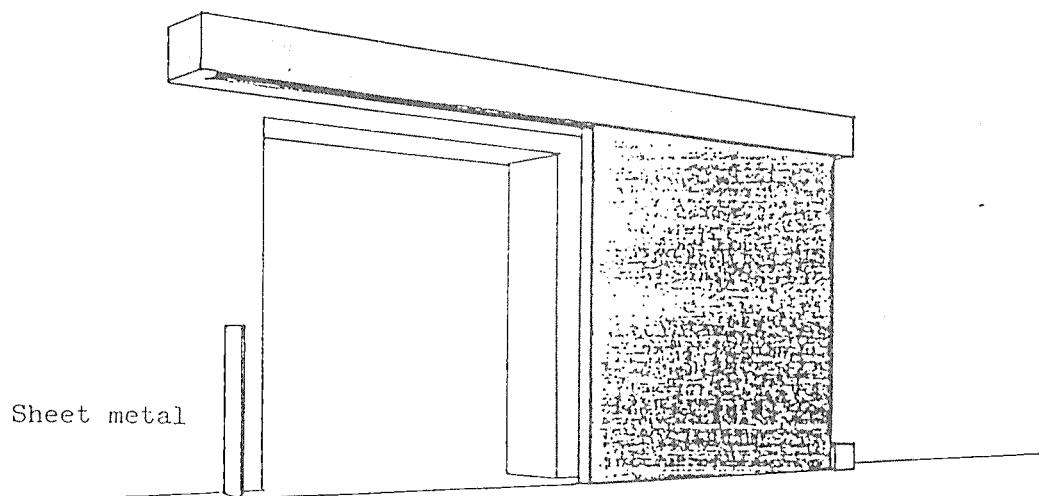
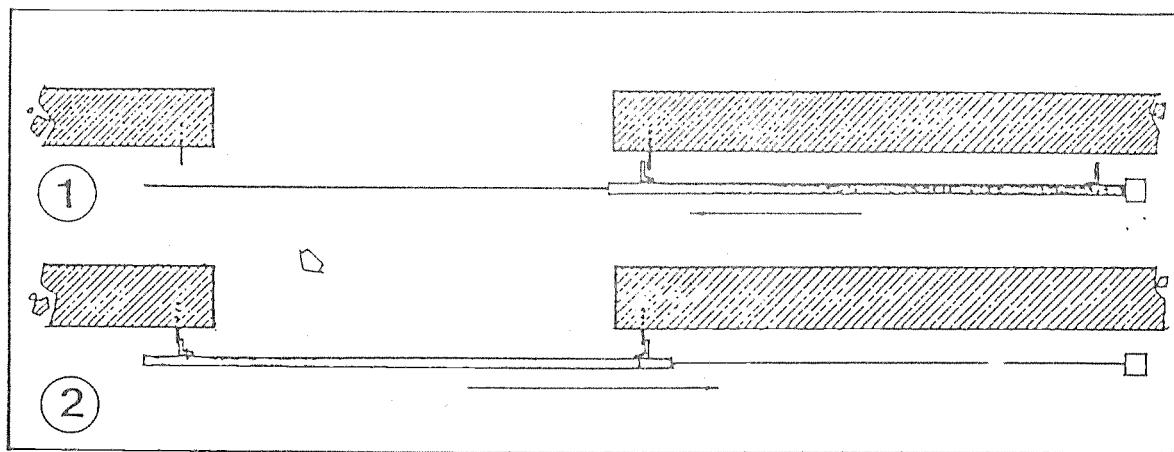


Figure 21: Sliding door with rodent proofing

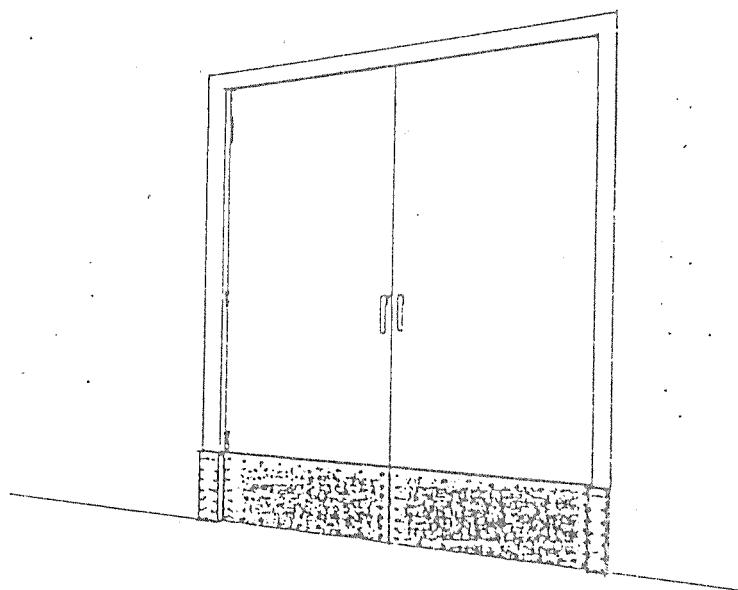


Figure 22: Wooden door with rodent proofing

should be replaced, e.g. by the storekeeper provided he knows that sheets must be fitted with a minimum side lap of one corrugation and a minimum end lap of 0.20m. Special nails including a sealing washer must be used. The nails should always be placed at the crown of the corrugation, never in the trough (see Figure 23). When a large area reveals damage in the roof, the work should be done by skilled roofers; such works must be properly planned so as to be completed before the rainy season.

ii. Rendering maintenance

The storekeeper must check all cracks and/or loose areas which occur in the rendering; such damage results from the weather and the normal wear of the building. As they can harbour insects they must be repaired; small repairs can be made by the storekeeper. Using a hammer and chisel defective coating is properly removed. The area so cleared is then roughened which allows better adhesion of the coating, then brushed to remove all concrete chips and dust, and finally well-dampened. Mortar can then be applied with a hawk and a trowel. Mortar should not dry out too quickly, which may result in cracking due to shrinkage; it is therefore necessary to keep the repaired area damp, especially when this is exposed to sun. The method consists in covering such an area with old bags and wetting these at regular intervals. Figure 24 shows the different stages of the process.

iii. Door frame repairing

Walls often deteriorate round the door frame and at fixing points. Storekeepers must repair the walls using the method described above.

iv. Painting and colour-washing

Local repairing of paint and colour washing can be done by the storekeeper. However, if the whole store needs attention a specialized contractor should be contacted.

v. Cleaning of insect screens

Cleaning or replacing mosquito netting used on ventilation openings will be quite easy if this is installed on removable frames (see the chapter on building design).

vi. Lubrication of door hinges and locks.

vii. Cleaning of drains and downpipes from the roof (when these exist) which may be blocked with weeds, dead leaves, moss, sand, etc.

viii. Maintenance of access to buildings

Heavy circulation of vehicles (such as lorries, carts) deteriorates the access space by creating ruts or deeper hollows. These areas should be stabilized periodically by filling them e.g. with rocks laid on edge covered with finer stone, so as to provide access to the store throughout the year.

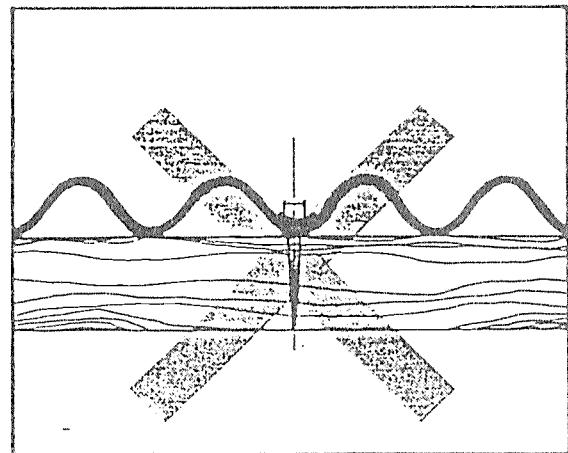
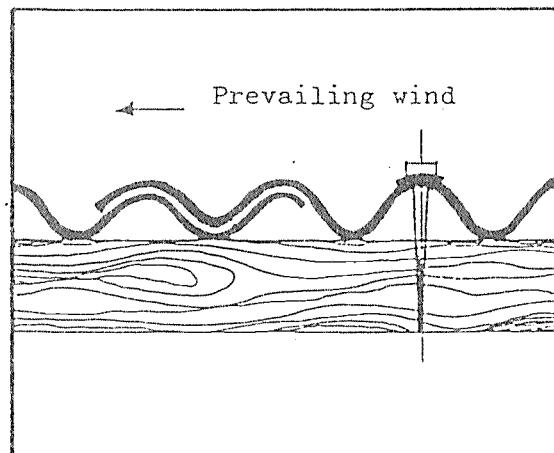
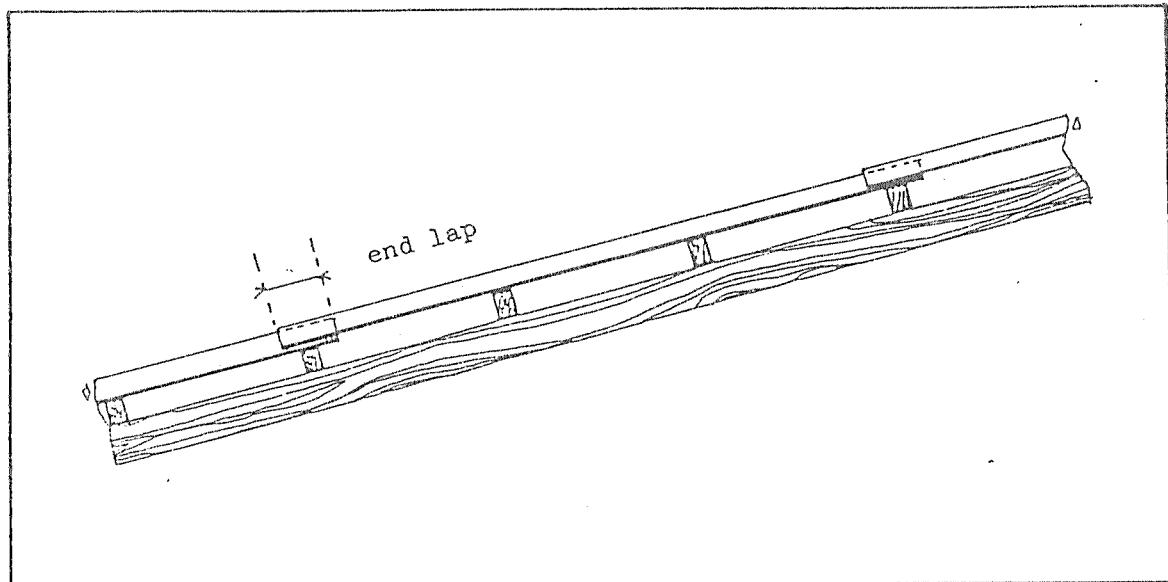


Figure 23:

Laying roof sheets

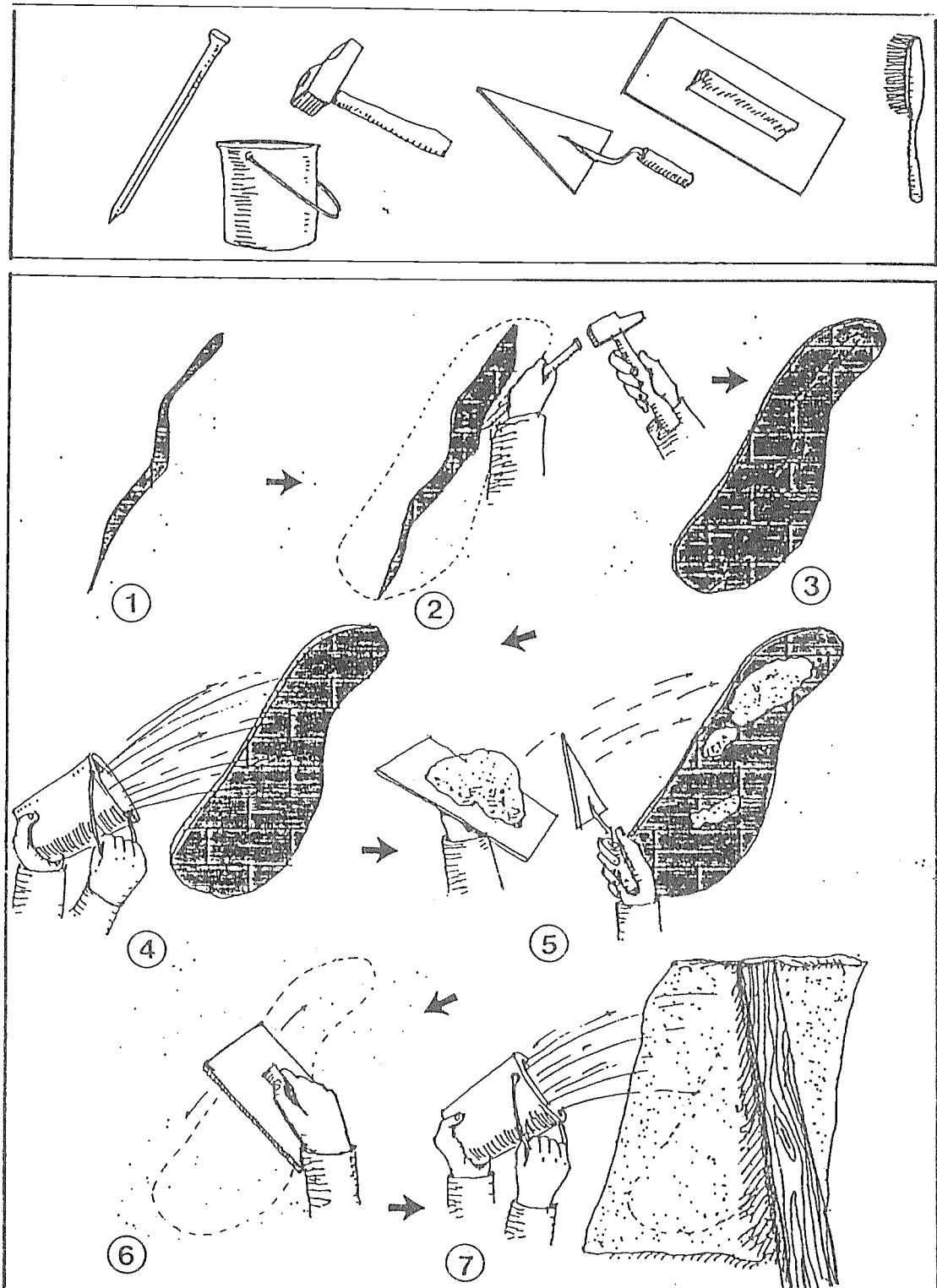


Figure 24:

Repair of rendering (cracks)

Repair of rendering

- Basic tools:

- Chisel
- Bucket
- Hammer
- Trowel
- Hawk
- Brush

- Stages:

- 1: Checking cracks
- 2: Removing the defective coating
- 3: Brushing of the cleared area
- 4: The area is well dampened
- 5: Mortar laying
- 6: Smoothing with the hawk
- 7: The area is kept damp for a few days.

ix. Repairing the wire and/or wooden gates fencing the area round the store.

x. Routine works in annex premises, such as the maintenance of water pipes and electrical installation.

(b) Major maintenance works

For any major work that requires corresponding skills, specialized craftsmen should preferably be employed. As these repairs may take a long time and cause disturbance to the regular store management, they should be properly scheduled so as to be carried out during the off-season. Such repairs mainly concern the following points:

- Partial or complete repair of the roof.
- Repair of the roof frame.
- Partial repair of the building frame.

Soil settling can result in deep cracks in columns, ringbeams, and/or walls that must be repaired. Reinforcement of the foundations may be needed.

- Repair of rendering and paint works.
- Repair of floor slabs showing cracks.
- Repair of electric circuits.

Regarding such repairs, the storekeeper should only evaluate the degree of deterioration involved and inform his director, who should then decide whether the repair must be undertaken.

C. WAREHOUSE EQUIPMENT

1. Basic equipment

To provide good conditions for storage and management, stores must be equipped with several machines. Some of them are absolutely necessary and others desirable, such as handling equipment that reduces the work load of warehouse staff.

In addition to the laboratory equipment considered in Chapter 3 the following should be considered.

(a) Weighing equipment

Conventional mechanical balances with a capacity of 200kg are generally used in stores. The number of available scales varies depending on the size of the storage centre. Nevertheless, the number of scales should be reasonable otherwise bottlenecks will occur at grain reception. Balances should be periodically checked.

(b) Handling equipment

N.B. The use of hooks should be totally prevented as they cause heavy damage to bags.

Sack trucks (Figures 25)

In many cases the handling of grain bags is totally manual that is, workers carry the bags on their back. Such excessively painful work can be alleviated by using metal or wooden framed sack-trucks with rubber-tyred wheels.

Flat-belt conveyors (Figure 26)

This equipment is used for back stacking. It consists of a rubber belt with transverse slats carried on a metal conveyor; the unit is mounted on a wheeled frame and is powered by an electric motor or an I.C. engine. A winch device allows the conveyor inclination to be altered. This equipment can be 6 to 10m long. Although frequently used in large depots, it is unsuitable for small stores due to the ground area needed. In small stores, mobile sack-lifters will be preferred.

Mobile sack-lifters (Figure 27)

These are well-suited where the ground area available is limited. They can easily be moved in the store gangways. They consist of a platform that is moved along a vertical metal frame by a winch powered by an electric motor or an I.C. engine. The 90° rotation angle of the platform facilitates bag loading; furthermore, as this equipment can be placed directly along the stack walls, it allows easy and proper stacking; nevertheless it only works on a unit basis while flat-belt conveyors allow continuous handling of sacks.

(c) Reconditioning equipment

If a consignment looks of poor quality, that is, showing damaged bags and/or a high proportion of infested grain and foreign matter for instance, it may be necessary to recondition the commodities so delivered. In such a case a reconditioning installation may be of interest; this will consist of the following machines:

- an auger equipped with a hopper for unloading bags
- a seed-cleaner
- a continuous insecticide treatment unit
- another auger
- a bagging scale
- a bag sewing machine.

Such unit is shown in Figure 28. As electric current is required to operate the unit, it can be obtained by connecting the store to the national grid network or installing a generating set on the site. The reconditioning unit can be installed in a separate shed or in the working area previously defined.

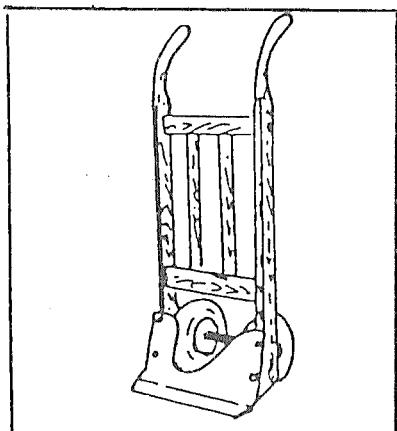


Figure 25: Sack truck

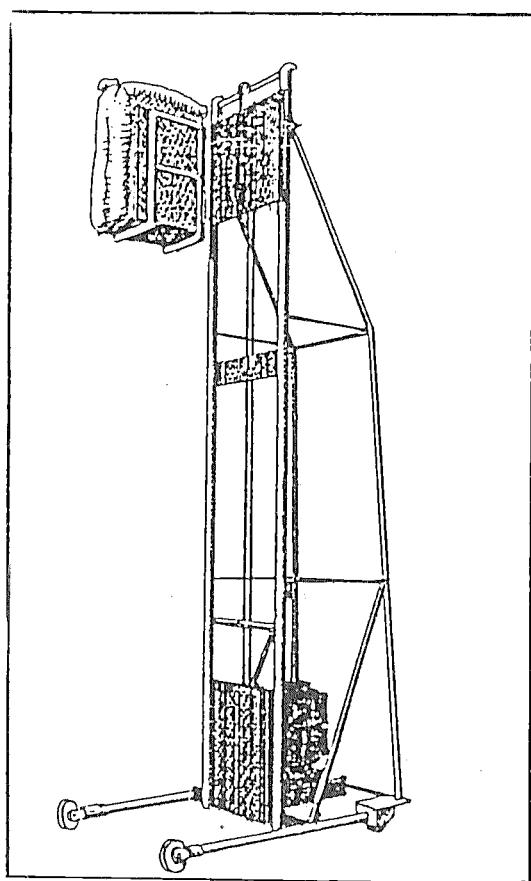


Figure 26: Mobile sack-lifter

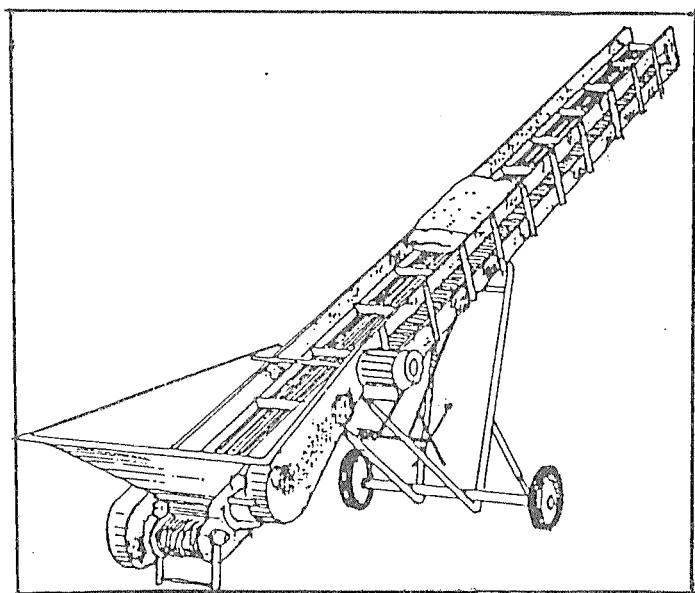


Figure 27: Bag conveyor

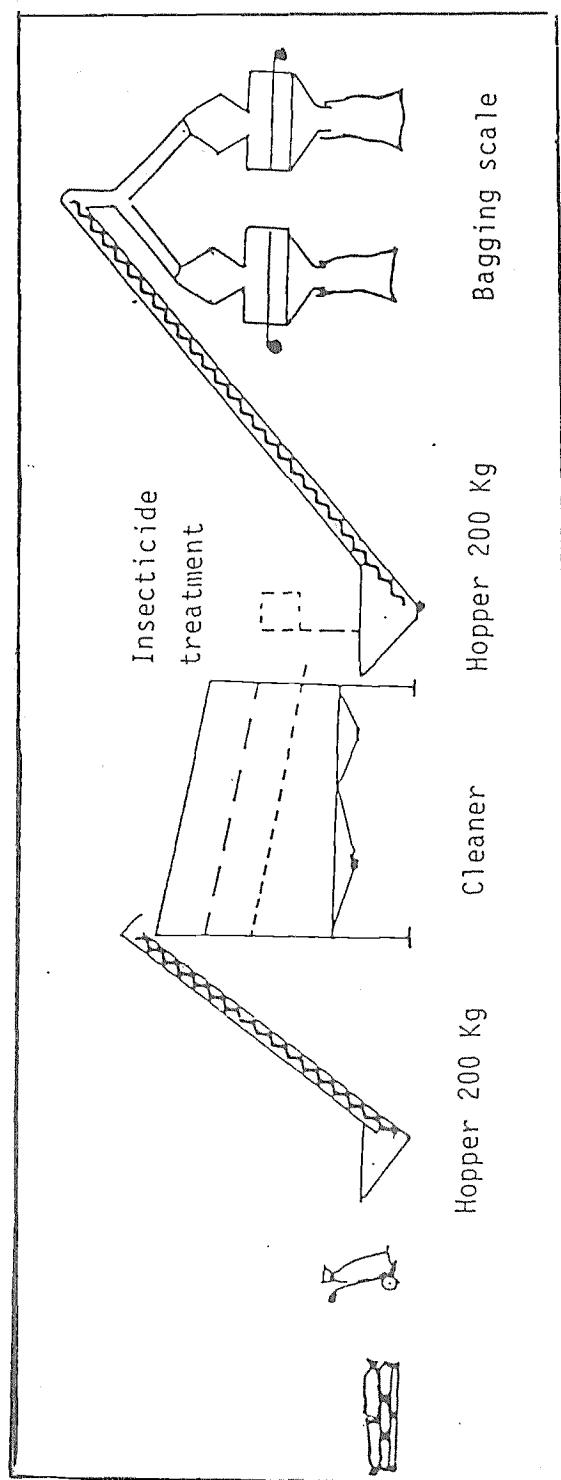


Figure 28:
Re-conditioning unit

(d) Pest control equipment for stored commodities and buildings

Mainly equipment for insecticide treatment on grain (such as dusters, sprayers, and mist blowers). This equipment will be described in the chapter on insect control.

(e) Cleaning equipment

Without going further in the matter, some small simple equipment must obviously be available in stores to allow daily cleaning (such as brooms, dustpans, brushes).

(f) Bags and pallets

Bags and pallets can be considered as warehouse equipment.

Bags

Fabric sacks are used for bagging many crops, especially grains. In the past there were only bags made of vegetable fibres (such as hemp, flax, cotton, sisal and jute). Today, because of their prohibitive price, hemp and flaxen fabrics have been practically abandoned as bagging materials. Cotton bags are still used but only for some processed products sold with an added value (flour, sugar). Sisal bags are mainly used in sisal producing countries (Brazil, Mexico and some African regions). Nevertheless sisal is rough to the touch and jute is therefore preferred to it; this is now certainly the most commonly used in the world. Presently, jutebags, that are essentially made in India and Bangladesh, but also in Thailand and China, are sometimes in competition with bags made of polypropylene coming from the EEC. The respective advantages of the last two types of bags are compared below.

Table 4/2. Brief comparison between jute and polypropylene bags

	Jute	Polypropylene
Price	—	Higher
Weight	Heavier	—
Mechanical resistance	—	Higher
Moisture resistance	Liable to rot	Rot proof
Ultraviolet resistance	Good	Bad (but some are u.v - proof)
Liability to slippage	Low	High
Stacking height	Up to 6m	Limited to 3m because of the slipping effect

As far as stores are concerned, the choice of the type of bags to be used is important because, as this will determine the stack height, it will also determine the effective storing capacity of the stores. In any case, each store must have a stock of new bags for reconditioning purposes when a consignment reveals damaged bags (e.g. rotten, torn, infested bags). Old bags should be burnt. New bags should never be stored in the warehouse itself but in separate premises. It is also worth recording that the use of handling hooks should be forbidden because this implement will greatly reduce sack life.

Pallets

Warehouses are usually provided with pallets used as base platforms on which the bag stacks are constructed. Pallets avoid direct contact of bags with the floor and so prevent possible damp from the floor reaching the produce. Their use is therefore absolutely necessary in stores with a poorly watertight floor or with openings (doors, ventilators) that may let in water. As a prudent measure they are also recommended for stores located in humid areas. On the other hand, in dry areas, when stores have been properly built that is, all requirements are satisfied (floor provided with a vapour barrier and well-laid floor finish) it does not seem really necessary to use pallets. As their laying out, management and storage usually constitute cumbersome tasks the use of pallets should, where possible, be avoided. Pallets should not be excessively heavy so as to be easily moved. Figure 29 illustrates two types of pallets usable for dunnage.

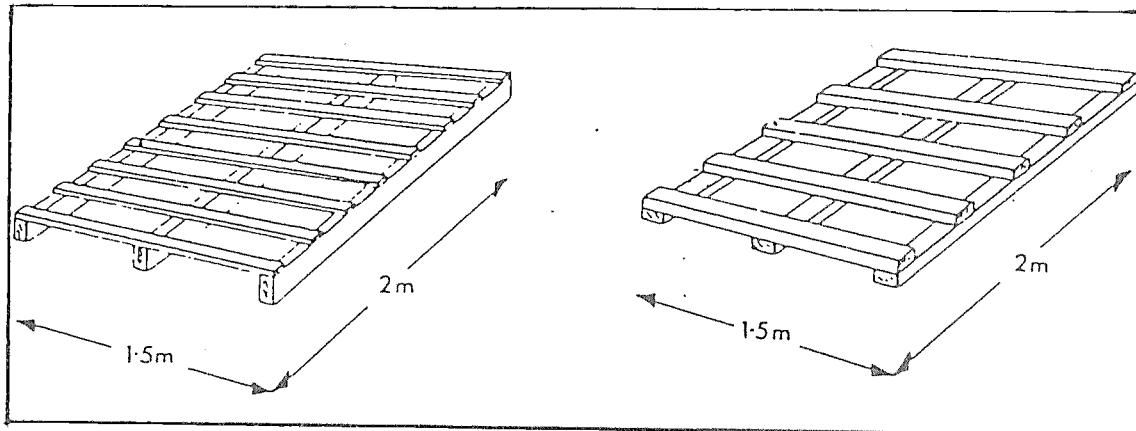


Figure 29: Pallets for dunnage

2. Maintenence of equipment

As far as equipment of the "expendable products" type is concerned such as bags and pallets, their maintenance mainly consists in repairs (replacing the broken elements of pallets for instance). Regarding other equipment previously mentioned, the maintenance required is that usual for agricultural power-driven units, for which some principles can briefly be recorded as follows:

- the equipment must be stored under cover;
- all bearing surfaces and working parts (chains, wire-ropes) should be greased;
- all tanks should be emptied;
- I.C. engines should be maintained properly (cleaning, lubrication, oil change);
- all worn parts should be replaced (such as belts, etc.)

Although some repairs need to be made by a skilled specialist, the regular maintenance of the equipment primarily rests with the storekeeper who should be adequately trained.

D. TECHNICAL MANAGEMENT OF STORED PRODUCE

1. Fundamental principles

The technical management of stores must satisfy some relatively simple parameters which are as follows:

- knowledge of the store capability according to the number of separate batches of produce;
- separation into batches according to the commodities involved and proper stacking, that is, stable and easily accessible stacks;
- obtaining the best storage possible throughout the storage period by:
 - storage in safe buildings offering good conditions and properly protected from predators;
 - accepting only good quality consignments or reconditioning those that do not seem acceptable;
 - assuring safe storage through good hygienic conditions inside and outside the store;
 - checking the stored produce on a regular basis and taking control measures when required.

- Issue of produce only against valid vouchers and application of the FIFO principle, i.e. bags taken First In should be First Out.

- Maintenance of the buildings and equipment.

2. Layout of produce within the store

(a) Stack location

The produce to be stored in a warehouse should be divided into separate batches. For this purpose paint marks can be drawn on the floor of the warehouse to serve as boundaries for the proposed back stacks. This should be done taking into account that a free space 1m wide is needed between stacks and walls. Handling gangways must also be provided for, facing the doors and according to the major axis of the warehouse. Regarding small stores or/and stores for long-term storage with a low turnover, the gangway width can be reduced to 2-3m so as to maximize the storage area. (*) On the other hand, for stores where loading-unloading operations are frequent (e.g. transit warehouses) the alleys should be increased to 4-5m to allow easy handling and use of equipment such as sack conveyors of the flat-belt type. Figure 30 illustrates a possible arrangements of separate batches within a warehouse.

(b) Stacking

N.B. Before any storage, the warehouse should offer perfectly safe conditions (i.e. it should be clean and have been treated).

Pallets should previously be installed in the area provided for stacking (floor paint-marked as described in the preceding section). The quality of pallets must be checked (e.g. there should not be any protruding nails as they may damage the bags). Every stack is then built layer by layer with special care regarding sacks at the edge of the stack. To allow good stability there must be an overlap in each successive layer. Figure 31 shows different stacking patterns. In any case one bag should always be covered by two bags (i.e. one bag in a layer covered by two bags in the following layer). To improve stability, stacks must be constructed with their walls leaning slightly towards the centre of the stack; with polypropylene bags, as polypropylene is an excessively slippery material, such leaning should be increased. Stacks can be pyramid-shaped; the stack height is commonly limited to 1m below the top of the building wall for inspection purposes. Other constraints can also limit the height; these are as follows:

- stack dimension: stack height should never be greater than stack width;

(*) In some cases, e.g. small stores for security stocks, handling gangways may be totally eliminated and the stock arranged in one stack only, to allow optimal use of the space available in the building.

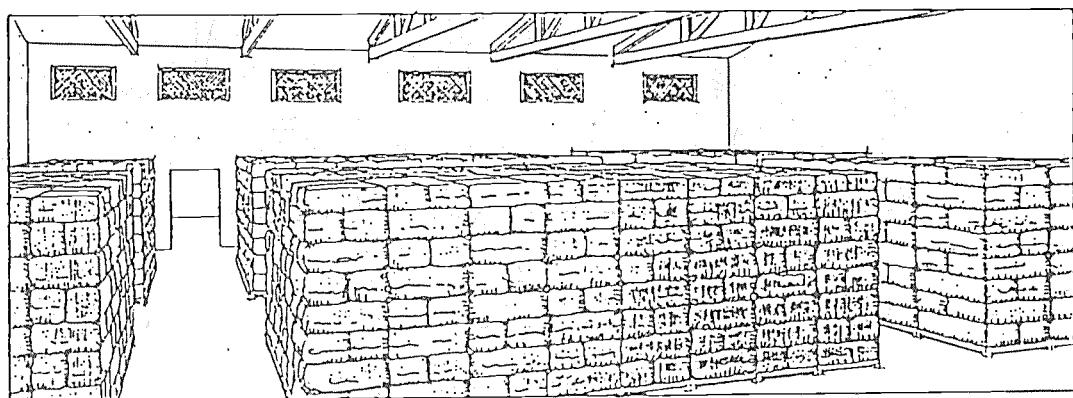
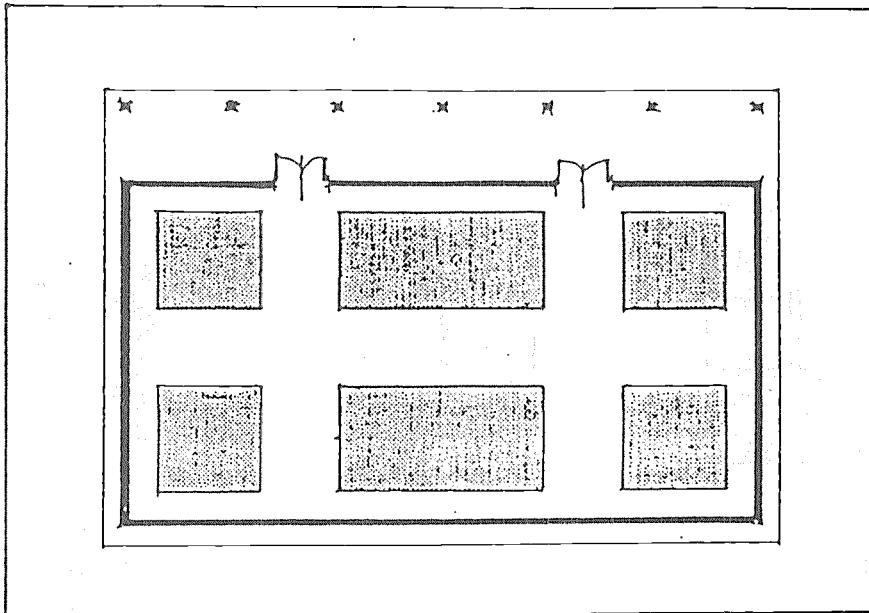


Figure 30: Separate stacks in a warehouse

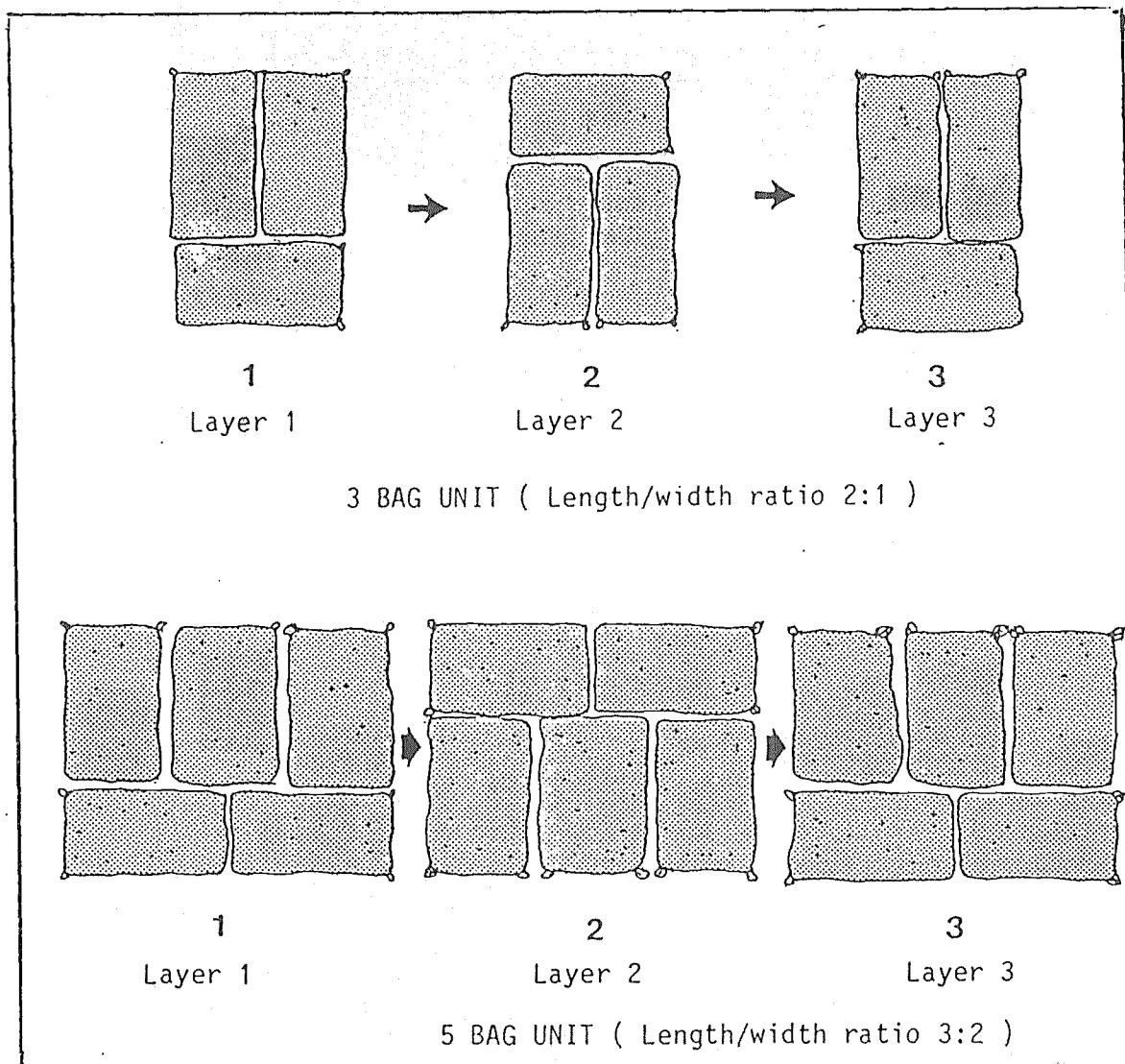


Figure 31: Stack layer patterns for two types of sack

- the material bags are made of (polypropylene or jute);
- nature of the stored produce; for "brittle" commodities (such as flour and milled rice) the stock height should be limited to avoid very heavy pressure on the bottom bags;
- sometimes, the size of available fumigation sheets;
- labour skill (with unskilled workers it can be dangerous to build excessively high stacks).

Regular stacking will allow easy counting of bags; this will only consist in multiplying the "basic unit" (i.e. the number of bags per layer according to the stacking pattern involved) by the number of layers (all the bags being necessarily equal in size and nature). After each stack completion a card should be established that will indicate the type of commodity, the volume of stored produce (number of bags), intake and stacking dates; the card should be pinned on a small wooden plate, covered with a plastic sheet then fastened on the stack wall; it should be possible to refer to at any time. Stack cards should be up-dated throughout the storage period and should particularly record all the pest control treatments applied during the period.

3. Storage management and hygiene

Inspections

During storage, stores should be inspected at regular intervals so as to check the condition of the stored produce and also of the building.

Inspections may be scheduled as follows:

- Every day: a rapid inspection of all the stores. This will be a visual inspection, that may be carried out at the end of the afternoon before closing the stores and will allow the detection of any new problems.
- Every week or every fortnight: a more careful inspection aiming at knowing with precision the condition of the stored produce and identifying all possible causes of deterioration in storage conditions, such as:
 - Signs of hot spots.
 - Development of moulds.
 - Insect and rodent attacks.

Such weekly or fortnightly inspections should not be only visual. Every stack should be checked, the seams of bags examined and ears of bags opened, as these constitute hidden places, protected from light, where insects can often be found. It is also necessary to inspect the top of stacks by randomly lifting some bags so as to identify any sign of infestation. Any grain spillage between bags at the bottom of stacks should be examined because this can often reveal rodent attacks. It is better to carry out these inspections at dusk because it is often

at this time of the day that insects are the most active. These inspection should also include probe sampling, the analysis of which will reveal some grain characteristics (mainly moisture content and degree of insect infestation). Inspections carried out in stores should also note signs of rodent attacks (such as presence of droppings, hairs, in the alleys and/on the bags, greasy smears left on walls).

- Every month, an overall inspection including:

- check of the stored produce;
- checks of the building elements (roofing, walls, floor, etc.)
- check of surroundings (cleanliness of the site, conditions of drains, etc.).

Nevertheless the frequency of such inspections can vary according to circumstances. When there are heavy risks of deterioration of the stored produce (e.g. humid and hot season, buildings of poor quality), inspections should be more frequent, while they can be less frequent when storage conditions seem good (e.g. dry season, buildings of good quality, adequately dried produce).

Hygiene

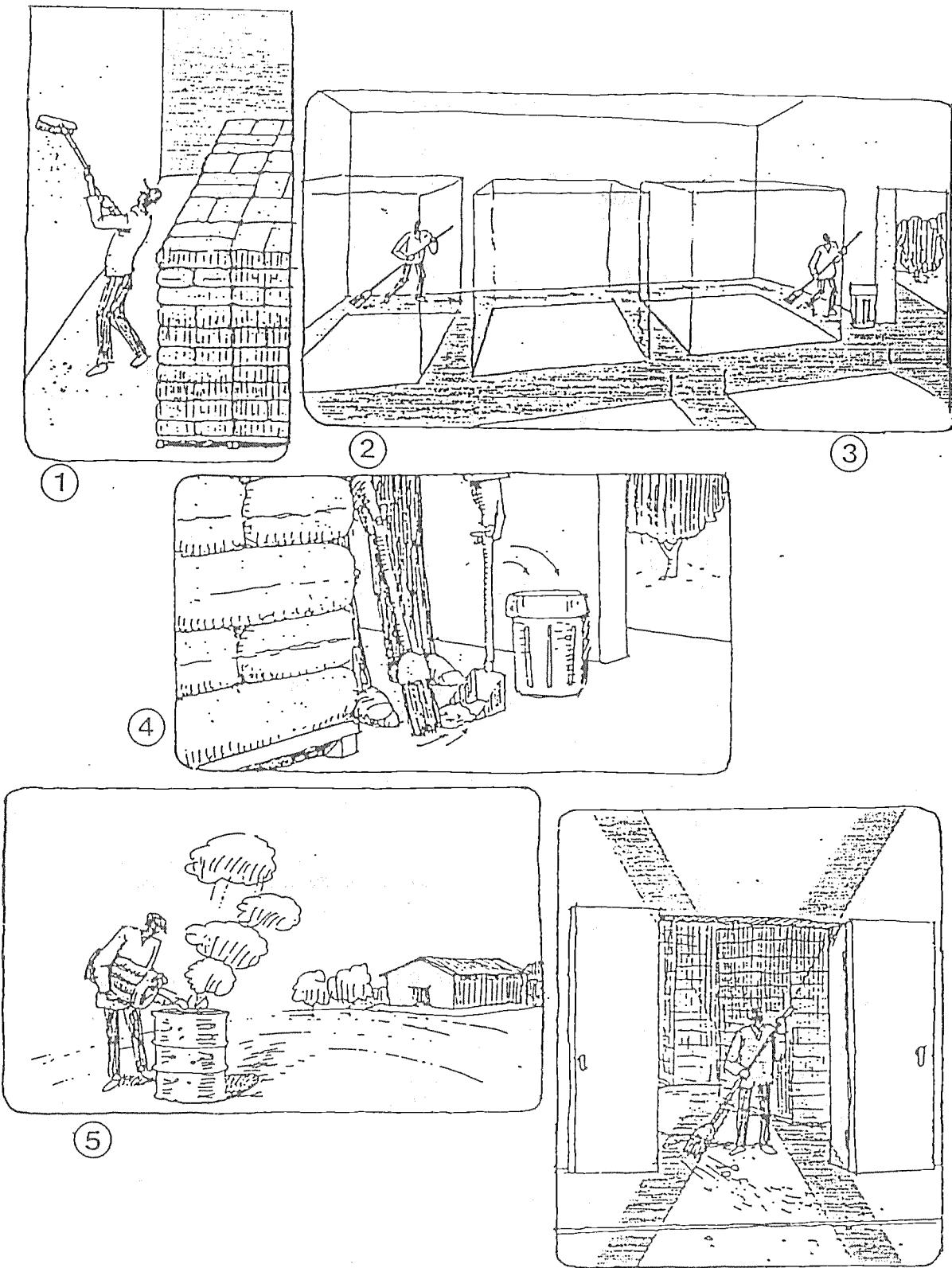
Good hygienic conditions in buildings are a requirement for safe storage. They also constitute one of the main preventive pest control methods.

The floor of stores should be cleared every day. Alleys between stacks should be swept from the rearside of the store to the doors; sweepings must not be thrown outside but put in a metal dustbin to be burnt (e.g. in a perforated can) outside the store as illustrated in Figure 32. If there is a large amount of grains within the sweepings, they can be recovered by sieving, then re-bagged after being treated.

Every month, thorough and careful maintenance operations should be carried out; these will include the cleaning of walls, beams, door frames and stacks, before sweeping the floor; at the same time, mosquito netting mounted on removable frames should be removed from ventilation openings to be cleaned and replaced if necessary. The surroundings of the stores should also be cleaned so as to provide a wide area perfectly clean and tidy (i.e. free from refuse, bushes and weeds) all around each store.

Ventilation control

As described in Chapter 2 a moisture and temperature balance (Equilibrium Moisture Content, EMC) exists between the air and the grain when they remain in contact for some time. The temperature and relative humidity of the external air vary according to the climate, season, daytime period (diurnal-nocturnal difference). Depending on the values such temperature and relative humidity will reach, it is important to be able to control the air flow entering a store, essentially by acting on ventilation openings. It is generally claimed that with a low relative humidity of the external air (i.e. below 65 percent) a store can be ventilated and the ventilation openings must be



- 1: Walls brushing.
- 2-3: Sweeping of floor (from the rear side to the doors)
- 4: Picking up of the sweepings. 5: Burning of sweepings.

Figure 32: Warehouse cleaning

closed when the relative humidity is over 70 percent, to prevent grain from re-humidifying. This is not perfectly right because temperature is not taken into account in spite of its paramount importance as far as ventilation is concerned. In effect, ventilation openings can be left open in the store, even if the relative humidity of the external air is more than 70 percent (rainy weather, night-time for instance) providing that the grain and the external air is more than 5°C. In contrast, one may be led to close ventilation openings even if the air is dry outside the store, especially if the temperature outside is higher than inside.

It is part of the storekeeper's function to control the ventilation system within the store. He should therefore have measuring instruments (hygrometers, thermometers) that will allow him to decide when he must open or close ventilation openings according to weather variations. The measurement of air characteristics is described in Annex 2.

E. OPEN-AIR STORAGE

Open-air storage refers to the various bag-storage methods that are not carried out inside "solid-wall" buildings. They mainly concern pyramid storage and storage in flexible silos.

1. Pyramids

In some countries with a dry climate pyramids of bags are built for storing produce such as unshelled groundnut or cowpeas.

Storage areas, which should always be located on raised ground (hillocks) will consist of a concrete or asphalt platform so as to resist moisture penetration from the ground and prevent termite attack. The platform can also consist of a layer of concrete blocks covered with a damp-proof layer (tarpaulin or polythene sheet). For short-term storage (a few weeks) a platform can also be made, after removing the topsoil, from a thoroughly tamped layer of laterite treated with an insecticide against termites.

Bag pyramids left in the open-air during the dry season should be covered with tarpaulins when risks of rain appear. The tarpaulins covering the base of the pyramid must be laid out first. They are fastened by means of ropes that pass over the top of the pyramid and are tied to the other side with counterweights (e.g. heavy stones); the top of the pyramid is then covered with a tarpaulin also fastened by means of ropes and counterweights; this one must be placed so as to overlap the lower tarpaulins, as shown in Figure 33. A trench should be dug all around the base of the pyramid to drain the rainwater running down the tarpaulin.

Tarpaulins are waterproof, but generally neither gas-proof nor vapour-proof because they should let out water vapour and prevent the stored produce from condensation; due to these properties they cannot be used as fumigation sheets.

The main advantage of pyramid storage is that it allows a rapid laying out of stocks whilst requiring a low investment cost. Nevertheless as this method does not give any protection against insect and rodent attacks, it can only be applied for short-term storage (i.e. a few months).

2. Storage in flexible silos

Storage in flexible silos is a practice that has mainly developed within the framework of the emergency stocks required during drought periods in the Sahelian countries.

Description (Figure 34)

Silos, in the shape of a circle, consist of two parts:

- The cylindrical lower part made of a 2.5m high welded galvanized wire-mesh lined with a thick plastic sheet (Butyl 12/10mm - 2 ply) that covers the side and the floor of the silo; the platform on which the silo is installed should be of concrete, otherwise, a perfectly level, firm, smooth and well-drained area can serve the purpose; this can be achieved by covering the ground with a 5-10cm thick layer of sand treated against termites.

- The upper part made of a cone-shaped tarpaulin installed after loading the silo and that should overlap the cylindrical base with a minimum 0.50m lap. The upper tarpaulin and the lower one are rolled together and tied to the wire-mesh with ropes; a rope-network keeps the upper tarpaulin in position so as to prevent this from flapping with wind.

These silos are protected from rodents by a 1m high ratguard made of corrugated iron sheet that is placed around the silo 0.50m from the wire-mesh wall.

Initially tarpaulins were made of butyl, but they did not resist solar radiation. The materials presently used vary according to manufacturers; so we can find:

- in the Cherwell silos, a Butyl/EPDM 2-ply sheet;
- in the Riedel silos, a PVC of the "Trévira" type.

These materials are more resistant to ultraviolet rays and weather.

Silo loading

Lower layers of bags are loaded through a 0.80 x 0.80m square opening, located in the cylindrical part of the wire mesh. When the first layers of bags are stacked, the opening is closed with a bolted steel plate; loading goes on by handling the bags over the wire mesh.

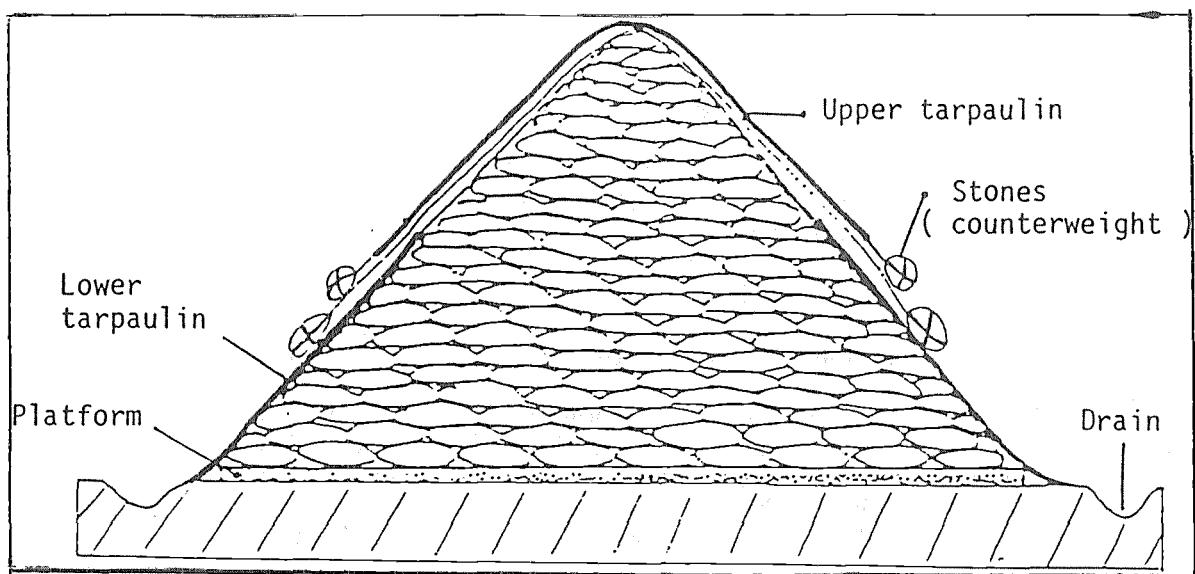


Figure 33: Use of tarpaulins for open-air storage

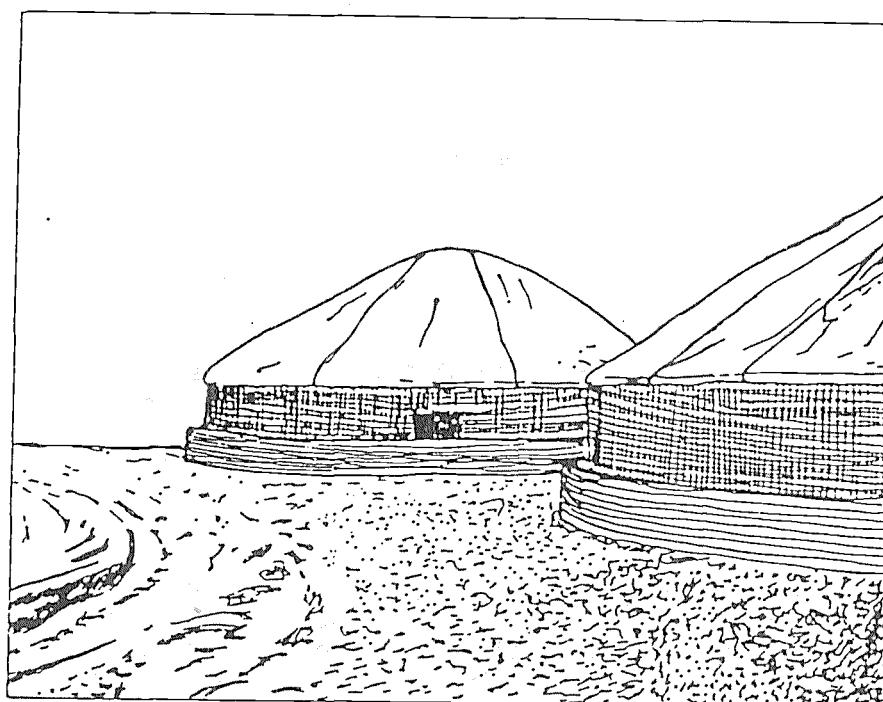


Figure 34: Flexible silo for bag storage

The capacity of these silos ranges from 250 to 1000 tonnes; those with a capacity of 500t are the most commonly used.

Advantages of storage in flexible silo

The flexible silo presents various advantages such as:

- Easy and rapid installation of the structure; 1 day is required for a 10-worker team.
- Low investment cost required (nevertheless, their amortization cost is higher than for conventional warehouses because of their low durability).
- Tightness allowing fumigation and safe storage provided the grain can be dried sufficiently before storage (10-11 percent m.c. for cereals).

The main disadvantages are as follows:

- Difficulty of produce handling. Loading and unloading operations are not easy and require skilled workers for cone - and circular - stacking.
- Low mechanical strength of the material used, which requires loading and unloading operations to be reduced to a minimum;
- Heavy risk of deterioration in stored produce (mainly due to condensation) when the produce cannot be dried sufficiently before storage.

Finally the use of flexible silos is limited to long-term storage, especially to food security stocks in regions with risks of severe drought (e.g. Sahelian regions).

CHAPTER 5

PEST CONTROL IN STORED PRODUCE

The protection of stored produce against external agents of deterioration includes both insect and rodent control.

A. INSECT CONTROL

1. Objective and techniques

The objective is to kill all insects present in stored produce at any stage of their development i.e. eggs, larvae, pupae and adults and to prevent infestation or re-infestation. As applied to food products, control of insect pests should not reduce their quality nor constitute a hazard to the consumer or to the pest control worker.

Many control techniques are used; that is biological, physical, mechanical and chemical techniques.

(a) Biological methods are still little developed; they essentially involve the sterilization of male insects; attacking insects by pathogenic viruses and fungi; development of new varieties more resistant to insect pests.

(b) Physical methods mainly include the following:

Cooling method: as the activity of insects slows down when the temperature decreases and ceases with temperatures below 10°C this principle is commonly applied in temperate and cold climates; it is not common practice in hot climates except for seed storage (refrigerated stores).

"Heat method": a 50°C temperature causes insect death. For produce that is run through a drier, all the insect population contained in the produce can therefore be eliminated, but for produce already stored it seems more difficult, if not impossible, to apply the "heat" method.

Modification of the ambient atmosphere: most insects die when the ambient oxygen content is below 1 percent. Such a value can be achieved by self-confinement (grain respiration reduced oxygen content while increasing carbon dioxide content). This principle is applied to some extent in South America for wheat and maize stored in airtight underground or semi-underground pits. It is also possible to artificially obtain an atmosphere poor in oxygen by replacing intergranular air with an inert gas (e.g. nitrogen or nitrogen-carbon dioxide mixture), as done in the Ivory Coast for storing cocoa in airtight silos; or also by storing the produce in vacuum bags (e.g. seed storage). The major factor of success for this technique is the perfect air-tightness of the structure used.

(c) Mechanical methods

Although grain turning and cleaning eliminate many adult insects, such operations are inefficient on insects at other stages of growth (e.g. eggs and larvae). For fine products such as flour and semolina a method consists in throwing, by centrifugal action, the infested product against a steel screen within a machine called an "Entoleter". The percussion kills insects at all stages; the technique is sometimes applied in flour mills.

(d) Chemical control techniques; these are presently the most commonly applied techniques to control insect infestations in stored produce and storage buildings.

2. Chemical control of insect pests

There are two main types of chemicals to be applied against insect pests; that is contact insecticides and fumigants. While the application and mode of action of these pesticides are different, they are complementary to one another. Fumigation constitutes a curative treatment while contact insecticides allow preventive treatment.

(a) Treatment with contact insecticides

The principal is to cover grain, bags, and buildings with a fine layer of pesticide that acts by direct contact with insects; the rapidity of the effect and the persistence may vary.

i. Contact insecticides (formulation)

Contact insecticides are composed of active ingredient (A.I.) mixed with additives. Various forms and formulations are available on the market, e.g. insecticide dusts, wettable powders, emulsifiable concentrates, liquid sprays ready for direct use, smoke generators, aerosols.

Insecticide dusts (I.D)

They are ready for use and generally contain 0.5 to 5 percent of active ingredient. They are used in admixture with grain or for surface dusting (e.g. bag layers).

Wettable powders (W.P)

The pesticide is marketed as a powder containing between 25 and 80 percent of active ingredient. Water should be added to obtain a spray mixture that will be applied with a sprayer. Wettable powders are widely used for treating buildings, especially porous surfaces (e.g. bricks, concrete blocks, non-painted timbers).

Emulsifiable concentrates (E.C)

Emulsifiable concentrates are composed of active ingredient and an additive insoluble in water; when they are mixed with water to produce a spray mixture they break up into droplets and give an emulsion. They

are used for treating non-porous surfaces (e.g. steel, plastic, painted timber) in buildings.

Other formulations

Liquid concentrates (L.C) ready for use as aerosols are composed of an active ingredient dissolved in light mineral oil. They are commonly marketed in the form of "aerosol bombs" and mainly used for environmental treatment within small stores.

Smoke generators that, as they burn, produce a "smoke" (an aerosol in which particles are solid) that spreads all over the inside space of stores are also used to control flying insects (moths).

Finally, insecticide strips that slowly release insecticide substances such as Dichlorvos can be used for space treatments; but they are more used in houses than in commercial warehouse.

ii. Insecticide chemicals

There are now many chemicals that can be used to control insect pests developing in stored produce.

Organochlorine insecticides, the best known of which are DDT and Lindane, have been totally condemned for treating food commodities because of their very high toxicity to human beings and domestic animals. Dieldrine can sometimes be used, but ONLY in ground treatment against termites.

Non-hazardous chemicals are presently available to control insect pests in grain and stores. These are synthetic pyrethroids on the one hand, and organophosphorus insecticides on the other.

The main contact insecticides presently used can be listed as follows:

- synthetic pyrethroids, i.e. bioresmethrin and deltamethrin;
- organophosphorus, i.e. bromophos, dichlorvos and malathion that are the oldest ones; they seem less efficient than new organophosphorus compounds such as pirimiphosmethyl and chlorpyrifos methyl or etrimfos and methacrifos.

Table 5/1 gives some characteristics for certain of these insecticides and corresponding application rates.

Synthetic pyrethrins seem very efficient against Rhizopertha i.e. an insect that will resist organophosphorus insecticides. Among these primiphosmethyl and chlorpyriphosmethyl prove efficient, have good persistence (frequently more than 6 months) and a low toxicity to human beings and domestic animals.

Table 5/1: Specification of Some Contact Insecticides

Active Ingredient (A.I)	DL 50 (mg/kg)	Formulation	Doses of A.I to be applied on grain (P.R.m)	Space treatment (stores) g/100m	Space (bags, walls) g/m	Remarks
Bioresmethrin	≥8600	E.C 25g a.i/1	1.5	-	-	Efficient against rhizopertha
Deltamethrin	140	L.C 12.5g/1 and 25g/1 I.D 0.05% W.P 2.5%	0.5-1	-	-	
Bromophos	4000- 8000	I.D 2% W.P 25% E.C 360g/1 L.N 400g/1	8-12	-	1	
Chlorpyrifos methyl ether	2140	L.C 240g/1	2.5	-	0.5-1	
Dichlorvos	50-80	L.C 500g/1 mist blower 5%	10	7.5	0.5-1	Crash action on insects. Dangerous chemical
Malathion	2800	I.D 2% E.C 500g/1	8	4	0.5-1	
Pirimiphos methyl	2050	I.D 2% W.P 25% E.C 500g/1	4-10	10	0.5	

Organophosphorous insecticides

iii. Application

Application techniques vary according to insecticide formulations, the material to be treated (i.e. grain, stacks, storage building), available equipment, operator skill, etc.

Grain treatment

Direct treatment of grain consists in covering the grain uniformly with a fine layer of insecticide; this is an easy treatment well-suited to bulk storage in which the insecticide is directly admixed with the grain by spraying at the foot of the conveyor. As far as bag storage is concerned, the insecticide should be added to the grain prior to bagging, either by mixing the insecticide dust with the grain if low volumes are involved (e.g. seeds), or by spraying at the foot of the auger at the level of the grain re-conditioning unit (as shown in Figure 28), if such a unit is available in the warehouse. However, as in most cases of bag storage direct treatment of grain is impossible, bag stacks only are treated.

Stack treatment

The purpose of such treatment is to prevent re-infestation as its efficiency to control insects within the grain is low. The treatment is applied as the stack is built, spraying or dusting each layer of bags. When the stack is completed, the stack walls and upper layer are sprayed; wettable powders are recommended.

Treatment of buildings

This concerns both surface treatment inside the warehouse and space treatment. Before any insecticide application, all surfaces to be treated should be thoroughly brushed and the store should be carefully swept.

For surface treatment, spraying is used. Insecticide formulations to be used and application rates mainly depend on the type of surface; detailed information is given in this respect in Table 5/2.

Table 5/2. Insecticide formulations and application rates for surface treatments

Type of surface	Recommended formulation	Application rate (1 of spray mixture/100 m ²)
Porous surfaces: brick, cement, concrete, mud, non-painted timber, jute bags	Wettable powders (W.P.)	5 10 20
Non-porous surfaces; steel, plastic, paint	Emulsifiable concentrates (E.C)	2.5

Insecticides are sprayed in an undulating movement from the top to the bottom of the walls in strips about 2m wide; spraying should be done starting from the rear of the warehouse to the door.

For space treatment, the main purpose of which is to control flying insects such as lepidoptera (moths) ready-to-use aerosols are applied as fog or smoke; thermal fogging can also be used and is a more common practice, as it produces very small droplets that remain suspended in the air for several hours.

Space treatments are generally carried out at the end of the day as flying insects are most active and as the store is being closed for the night. To be fully effective, space treatment should be carried out every day or at least three times a week when lepidoptera are detected.

iv. Methods and equipment

Dust treatment

This consists in applying insecticide dust (I.D) on grains or bags. For small volumes of grain to be treated, dusting can be carried out manually by shovelling with a scoop a pile of grain to which has been added the required quantity of insecticide; but as the resulting mixture is not homogeneous, treatment effects may be very uncertain. To improve the method a duster of the "churn" type can be used; this is composed of an iron drum mounted on an eccentric shaft as shown in Figure 35. The so-called "Fuffle" small mixer can also be used to treat the whole contents of a bag; in this mixer, grain and dust are poured into a drum provided with inside deflectors, where they are thoroughly mixed then delivered through a bagging spout located under the machine.

At a higher level of technology, especially in seed production centres, power-driven dusters are sometimes used; they consist of a seed hopper, a dust hopper, a drum equipped with a mixing auger and a bagging attachment.

Centrifugal fan dusters can be used to dust bag layers. These hand-operated or engine-drive machines deliver a continuous dust outflow, that will, however, depend on the operator's rate and level of dust within the hopper. Figure 36 shows a hand-rotary duster. Dusting efficiency is uncertain because the treatment unevenness frequently results in under-treated and over-treated areas.

Spraying

A variety of spraying equipment exists that divide insecticide liquid into droplets with a size ranging from 50μ to more than 200μ to increase application efficiency. Commercial formulations used for spraying are either liquids that dissolve in water to give a solution, solids that give a suspension when in water is added (wettable powders) or oily liquids that dilute in water to give an emulsion (emulsifiable concentrates). The mixture obtained when adding water to the commercial product is called a spray mixture. There are three spraying systems:

- Hydraulic spraying

In such spraying system, the liquid to be sprayed breaks up into droplets under the pressure resulting from the mechanical effect of a pump; the droplet size, which depends on the pressure and on the diameter of the nozzle used, is generally more than 100μ .

There are many knapsack sprayers of the pressure type that can be used for hydraulic spraying; the tank, with a 10 to 20 l capacity, is equipped with an agitator to prevent spray mixture from settling (especially if wettable powder is used).

Hand operated hydraulic knapsack sprayers are preferred as they allow a constant pressure to be maintained from a manually operated pump, giving proper evenness of application. Pneumatic sprayers (also called compression sprayers) do not give even treatment because the pressure on the liquid decreases as the liquid flows out. Figure 37 shows a hand-operated hydraulic knapsack sprayer.

- Air blast spraying (mist blowing)

In this system, the liquid insecticide under pressure is discharged in the centre of a blast, the impact of which causes the liquid to break up into small droplets. The spray so obtained is finer than with hydraulic spraying and forms a mist carried by the air stream.

Motorized knapsack sprayers consist of a tank with a capacity ranging from 10 to 12 l and a centrifugal motor-fan that forces a strong air stream into an air duct, at the end of which is located the nozzle to which is carried the liquid to be sprayed. A portion of the air flow from the fan is sent to the tank so as to agitate the spray mixture.

Such sprayers (Figure 38) are much used in tropical countries for the treatment of stored produce and also for standing crops. Some are multipurpose machines which can also be used as dusters.

- Thermal fogging

This type of spray is obtained by introducing an oil solution of insecticide at the end of a nozzle that carries a stream of hot gas (exhaust gas) from a spark ignition engine; the spray consists of very small droplets below 50μ in size, which form a white fog; the white colour is due to the oily nature of the liquid used.

Thermal fogging is used for space treatment in storage buildings; among the hand-operated machines available for thermal fogging, the most frequently used in tropical countries are the "Swingfog" (illustrated in Figure 39) and "Pulsfog".

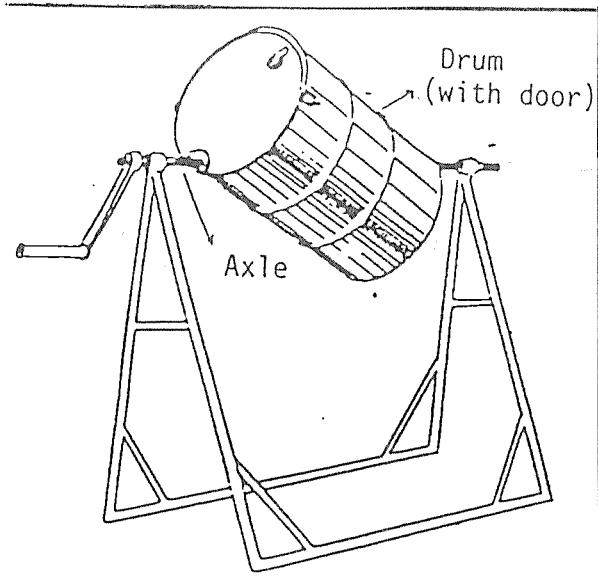


Figure 35: Dusting grain in a drum

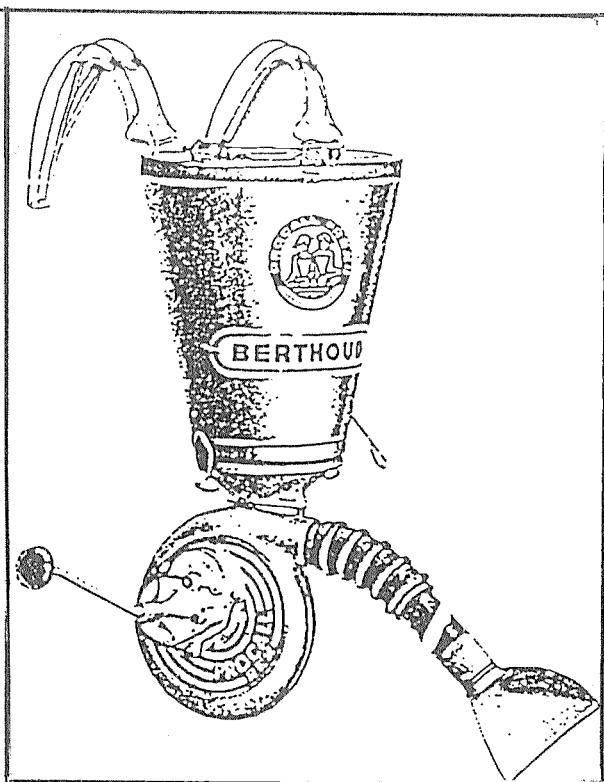


Figure 36: Duster

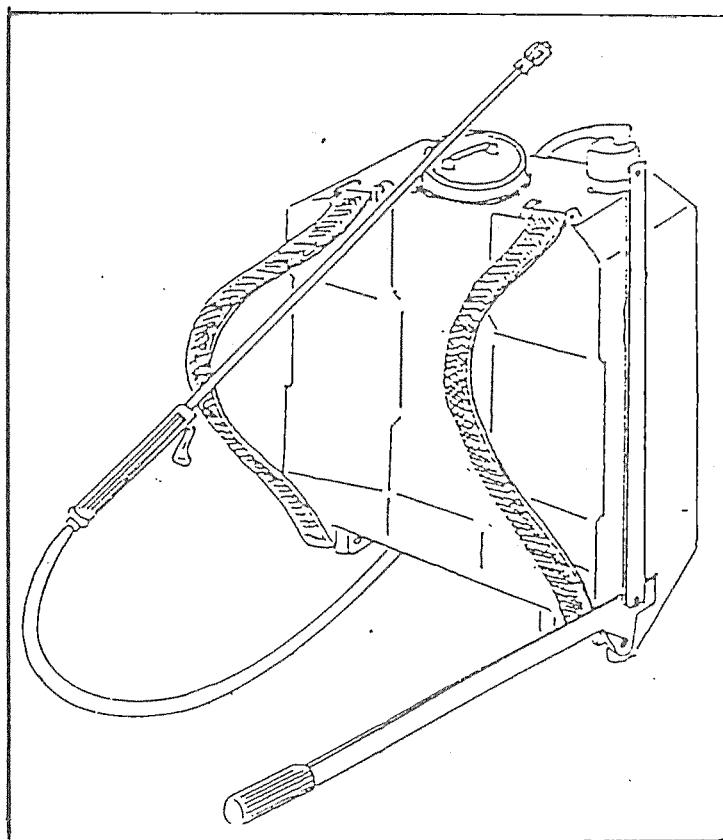


Figure 37: Hydraulic knapsack sprayer

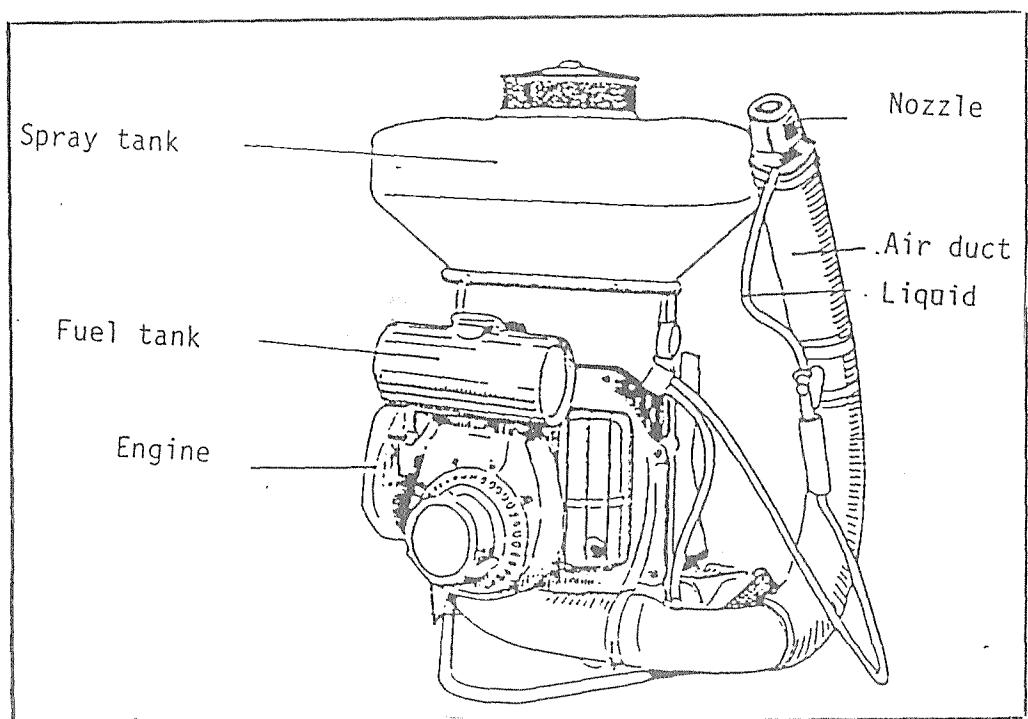


Figure 38: Motorized knapsack sprayer (mist blower)

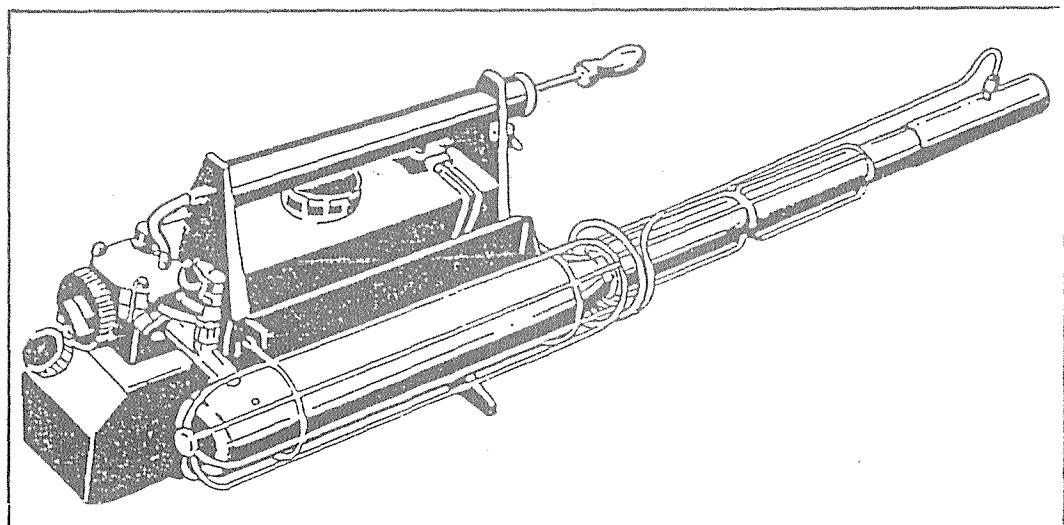


Figure 39: Thermal fogger ("Swingfog")

v. Example of insecticide spray preparation and dilution

Basic considerations on concentration and dosage

The concentration in a commercial insecticide is the quantity (in grammes) of active ingredient contained in the unit of volume or mass of the commercial insecticide.

Examples:

- (1) A 2 percent insecticide dust formulation means that 1kg of commercial insecticide contains 20 gr of active ingredient;
- (2) A 25 percent wettable powder insecticide formulation means that 1kg of commercial insecticide contains 250gr of active ingredient;
- (3) Regarding emulsifiable concentrates, it is necessary to carefully read the label attached to the product that indicates the concentration of active ingredient. In effect, the same concentration may be expressed in different forms; e.g. Actellic 50 EC means that the emulsifiable concentrate contains 50 percent of active ingredient i.e. 500 grammes of active ingredient per litre; and Folithion 500 EC also means 500 grammes of active ingredient (Fenitrothion) per litre of emulsifiable concentrate.

The spray concentration is the mass of active ingredient contained in the unit of volume of the spray mixture to be applied.

Example:

Prepare 1 litre of spray mixture at 7.5 percent active ingredient, from an emulsifiable concentrate of the Actellic 50 EC type.

- A spray at 7.5 percent A.I. means that in 1 litre (= 1 000ml) of spray mixture:

$$\frac{7.5}{100} \times 1\,000 = 75 \text{ grammes of A.I. are required}$$

- Actellic 50 EC means that 1 litre (= 1 000ml) of commercial insecticide contains 500 gr of active ingredient; as only 75gr of A.I. are required for the treatment, the quantity of commercial product necessary will therefore be:

$$\frac{1\,000}{500} \times 75 = 150\text{ml}$$

The preparation will then consist in mixing 150ml of commercial insecticide with 850ml of water, to obtain 1 000ml (1 l) of spray mixture at 7.5 percent A.I.

A simple formula gives the quantity (Q) of the commercial concentrated formulation (Ci) required to prepare a volume V of spray mixture at Cf concentration; this is as follows:

$$Q = \frac{V \times Cf}{Ci}$$

Q = quantity of insecticide to be used (in litre)
Ci = initial concentration in the commercial insecticide (in %)
V = volume of spray mixture required (in litre)
Cf = final concentration in the spray mixture (in %)

Applying the formula to the example above we shall;

V : volume of spray mixture to be prepared = 1 litre
Cf : concentration in the spray mixture = 7.5 percent
Ci : concentration in the commercial product = 50 percent

So, the quantity of commercial product to be used should be:

$$Q = \frac{1 \times 7.5}{50} \text{ 0.15 litres} = 150\text{ml}$$

Which confirms the result previously obtained.

- The application rate is the quantity (in grammes) of active ingredient to be applied per unit of treated matter (mass, surface area, volume).

Referring for instance to Table 5/1, the recommended application rates with pirimiphosmethyl are;

- For grain (mass): 4 to 10gr per tonne (i.e. 4 to 10gr of active ingredient per tonne of grain).
- For bags and walls (surface): 0.5gr per m² (i.e. 0.5gr of active ingredient per square metre of surface area).
- For space (volume): 10gr per 100m³ (i.e. 10gr of active ingredient to every 100 cubic metres of volume in store).

Regarding grain treatment, application rates are sometimes expressed in parts per million (ppm) that corresponds to 1gr per tonne (1 tonne = 1 million grammes).

Example of calculation

The purpose is to apply a contact insecticide on the inside walls of a store with the following dimensions:

length : 20m
width : 9m
height of walls : 5m
height to ridge : 6.5m

The inside face of walls is rendered; doors are of non-painted timber; the roof is of asbestos-cement sheets.

The purpose is to treat the store by spraying.

The available means are as follows:

Case no.1: one hand-operated sprayer (tank capacity : 20 l) and organophosphorus insecticide formulated as wettable powder 25 percent.

Case no.2: one motorized knapsack sprayer (tank capacity: 10 l) and an organophosphorus insecticide formulated as emulsifiable concentrate: 50 EC.

How should we proceed?

First: Determine the surface to be treated:

- Surface of one side wall: $20 \times 5 = 100\text{m}^2$
2 walls 200m²
 - Surface of one end wall: 5×6.5
 $\frac{\text{---}}{2} \times 9 = 51.75\text{m}^2$
2 end walls = 103.5m², rounded to 100m²
 - Surface of one roof slope : $20 \times 4.75 = 95\text{m}^2$
2 slopes = 190m², rounded to 200m²
- The surface to be treated is: 500m²

Second: Quantity of spray mixture to be prepared:

Assume the surfaces are fairly porous. Referring to Table 5/2 the application standard used is 10 litres of spray mixture per 100m²; as the total surface to be treated is 500m², the quantity of spray mixture required will be 50 litres.

Third: Application rate

Referring to Table 5.1, the application rate of 0.5gr of A.I. per m² will be used; for 500 m² the A.I. required will be:

$$0.5 \times 500 = 250\text{gr of A.I.}$$

Fourth: Quantity of commercial insecticide required to prepare the spray mixture:

50 litres of spray mixture should contain 250gr of A.I.

Case no.1: the 25 percent W.P., available means that 100gr of commercial insecticide contain 25gr of A.I. As the purpose is to obtain 250gr of A.I., 1 000gr (i.e. 1kg) of commercial insecticide will be necessary. Therefore the spray mixture needed will be obtained by mixing 1kg of

insecticide supplied in 25 percent wettable powder formulation with 50 litres of water.

Case no.2: the 50 EC supplied means that it contains 50 percent of A.I., that is 500gr of active ingredient per litre of concentrate. As 250gr of A.I. are needed, 0.5 litre of commercial insecticide will be required; the spray mixture will therefore be obtained by mixing 0.5 litres of the commercial product in 50 EC formulation with 50 litres of water (in reality with only 49.5 l of water if exactly 50 litres of spray mixture are to be obtained).

Fifth: Insecticide application

Case no.1: as the tank capacity of the hand-operated sprayer is 20 l, it can treat 200m².

The application will consequently be as follows:

- 1 full tank of spray mixture for the roof
- 1 full tank of spray mixture for side walls
- 1/2 tank of spray mixture for end walls

Case No.2: as the tank capacity of the mist blower is 10 l, it can treat a 100m² area.

In consequence the application will be as follows:

- 2 full tanks of spray mixture for the roof
- 1 full tank of spray mixture for each side wall
- 1 full tank of spray mixture for both end walls

vi. Limits of treatment with contact insecticides

When properly carried out according to recommended application rates, treatments with contact insecticides allow effective control of adult insects in stocks. They can constitute a preventive treatment for stored commodities. Some disadvantages should nevertheless be mentioned as follows:

- Residue problems may appear when the insecticide is directly applied on food commodities; nevertheless the low toxicity to human health of new insecticides reduces such disadvantages.
- Contact insecticides act on free insects; they have no or little effect on other development stages, that is eggs and larvae.

(b) Fumigation

i. Basic considerations

Definition

Fumigation is a treatment which consists in controlling insect pests within stored produce by means of a toxic gas called fumigant. A fumigant is "a substance that at a given temperature and pressure can be

produced in a gaseous form at a lethal concentration for a given living species".

Fumigant characteristics

Fumigants diffuse in the whole available space. Such diffusion is more or less rapid depending on gas density and ambient temperature. The tininess of gas molecules, the size of which is only some Angströms (1 : 10 million mm) allows fumigants to penetrate to the inner part of the grain and so to reach and kill all stages of insect life within (i.e. eggs, larvae and pupae). A portion of gas may be captured by adsorption on the grain surface or, less frequently by absorption within the grain, and produce insecticide residues if a chemical reaction occurs; this adsorbed/absorbed portion has no effect on insects; the greater the grain-gas contact area, the higher is adsorption, this increases as dosage, moisture content and exposure period increase, but decreases as temperature rises.

Concept of concentration-time product (CT)

Fumigation effectiveness depends on two main factors, i.e. actual concentration of gas and time of exposure of infested commodities to gas. The C.T. value (concentration-time) is expressed in gramme-hour per cubic metre (gr x h/m³). C.T. values to be applied to kill 100 percent of an insect population vary according to the fumigant used (phosphine or methyl bromide), target insects, temperature and time of exposure. Regarding fumigation with phosphine (PH₃), the values are given in the Wayman tables (Table 5/3.). For fumigation with methyl bromide the C.T. value to be applied is generally 200gr.h/m³.

The CT concept also means that there is a possibility of acting either on the time factor or on the temperature to obtain the appropriate toxicity regarding insects; therefore, theoretically a fumigation at high concentration applied for a short time would be equivalent to a fumigation at low concentration applied for a long time. In reality, reasonable limits should be observed. Fumigations with methyl bromide should last between 24 and 48 hours; in most cases a minimum time of 5 days is recommended for phosphine.

The toxicity of fumigants is effective only during the time the commodities are exposed to the gas. Fumigation is a curative treatment and fumigated produce can be re-infested.

Table 5/3.

PH3 toxicity to insects

Concentration-time value expressed in mg.h/l at/above which 100 percent of all stages of insect pests involved in tests were killed, at stated temperatures and times.

Temperature	Species	Time of exposure (days)			
		2	4	7	10
25°C	<u>Sitophilus oryzae</u>	—	158	48.5*	31.10
	<u>Caryedon serratus</u>	—	>30.6	33.8*	<14.4**
	<u>Sitophilus granarius</u>	>142	158	>45.8*	9.4
	<u>Ephestia elutella</u>	>142	9.3	8.0	9.4
	<u>Tribolium confusum</u>	—	>21.7	—	—
	<u>Lasioderma serricorne</u>	77.0	30.6	27.0	4.8
	<u>Sitophilus zeamais</u>	>142	87.0	>45.8*	4.8
	<u>Acanthoscelides obtectus</u>	>142	30.6	26.0	4.8
	<u>Trogocerma granarium</u>	38.0	30.6	13.6	4.8
	<u>Cryptolestes ferrugineus</u>	—	>8.3	<8.0*	<14.4**
	<u>Ephestia cautella</u>	77.0	3.3	3.7	4.8
	<u>Plodia interpunctella</u>	77.0	3.3	3.7	4.8
	<u>Ephestia kuhniella</u>	77.0	2.5	3.7	4.8
	<u>Ptinus tectus</u>	19.0	8.3	6.9	<2.8
	<u>Tribolium castaneum</u>	7.9	8.2	6.9	<2.8
	<u>Rhizopertha dominica</u>	77.0	30.6	3.7	<2.8
	<u>Cryptolestes pusillus</u>	7.9	8.2	<2.2	<2.8
	<u>Oryzaephilus surinamensis</u>	1.3	1.4	<2.2	<2.8
30°C		1 day	2 days	4 days	8 days
	<u>Sitophilus granarius</u>	—	>17.5	16.5	<8.0
	<u>Lasioderma serricorne</u>	—	>17.5	16.5	<8.0
	<u>Trogocerma granarium</u>	—	>17.5	16.5	<8.0
	<u>Acanthoscelides obtectus</u>	—	17.5	8.7	<8.0
	<u>Sitophilus oryzae</u>	—	>17.5	<4.5	<8.0
	<u>Sitophilus zeamais</u>	—	>17.5	<4.5	<8.0
	<u>Caryedon serratus</u>	—	>17.5	<4.5	<8.0
	<u>Cryptolestes ferrugineus</u>	—	>17.5	<4.5	<8.0
	<u>Ephestia elutella</u>	>9.4	7.0	<4.5	<8.0
	<u>Ephestia cautella</u>	>9.4	<2.4	<4.5	<8.0
	<u>Plodia interpunctella</u>	>9.4	<2.4	<4.5	<8.0
	<u>Ephestia kuhniella</u>	>9.4	<2.4	<4.5	<8.0
	<u>Rhizopertha dominica</u>	>8.1	<2.4	<4.5	<8.0
	<u>Oryzaephilus surinamensis</u>	2.2	<2.4	<4.5	<8.0
	<u>Tribolium castaneum</u>	1.1	<2.4	<4.5	<8.0

* 8 days

** 14 days

ii. Fumigants

The fumigants mainly used in hot regions are hydrogen phosphide (PH_3), also called phosphine, and methyl bromide (CH_3Br). PH_3 is the most commonly used because its application is much easier than methyl bromide.

Phosphine

- General remarks

The gas results from the decomposition, in contact with atmospheric moisture, of a commercial product consisting of metal phosphide (typically aluminium phosphide but also recently magnesium phosphide) and ammonium carbamate coated with wax; they can be supplied in several formulations, the most common are as follows:

Aluminium phosphide.

Pellets of 0.6gr each that releases 0.2gr of PH_3 (in flasks containing from 150 to 2000 pellets).

Tablets of 3gr each that releases 1gr of PH_3 ; they are supplied in tubes containing 30 tablets packed in tins containing 16 tubes.

Bags of 33gr of powder, that release 11gr of PH_3 each; bags are packed in tins containing from 10 to 20 bags. The bag formulation offers the advantage of enabling easy recovery of fumigant residue (a grey powder composed of aluminium oxide) after the gas is released.

Magnesium phosphide.

Several formulations exist i.e. pellets, tablets and plates of 110g that release 33g of PH_3 .

The product does not release gas immediately but only after being in contact with atmospheric moisture for 30 min - 1 hour; this reaction time obviously depends on the relative humidity of the air. In very humid air, tablets may decompose very quickly while in a dry atmosphere they may not decompose easily. In any case, the moisture content of the commodity should be more than 10 percent, or the RH of the air should be over 45 percent. PH_3 is a gas that diffuses very well and requires perfectly gas-tight conditions to be applied. Conventional building materials never prevent its diffusion and PH_3 easily diffuses through brick, "banco" and concrete; in contrast it does not permeate through plastic sheets. PH_3 can be corrosive to some metals (e.g. copper).

- Dosage rates.

In hot climates where the temperature of stored commodities is frequently about $25^{\circ}\text{C} - 30^{\circ}\text{C}$, dosage rates of 1-2gr/m³ applied for 4 to 5 days are effective.

Methyl bromide

- General remarks

Methyl bromide is supplied as a liquified gas in cylinders containing 20 or 40kg of bromide; for its application, liquid bromide should be vaporized through a heating system.

Heavier than air, it does not diffuse as well as PH₃ and frequently requires the use of an air-mixing system to allow uniform distribution throughout the fumigated enclosure. As this is a naturally colourless and odourless gas it is not easily detected and chloropicrin (lachrymatory substance) should therefore be added so as to allow its detection. Materials such as concrete, cement, brick and plaster are rather effective in stopping methyl bromide molecules which are bigger than PH₃ molecules; the gas does not dissolve in water but dissolves in fats, which can cause residue problems on some commodities such as oilseeds and cocoa; adsorption is higher than for PH₃.

Application standards are, for a temperature of about 20°C, a CT value of 200gr.h/m³. For fumigation of grain, dosage rates of 15 to 25gr/m³ are generally applied for 24h, considering that adsorption is very high for methyl bromide. The action on insects is more rapid for methyl bromide than for PH₃; insects are killed within 10-12 hours. Table 5/4 gives a comparison between the two fumigants mainly used in hot climates.

Table 5/4. Comparison of Phosphine Vs methyl bromide

Property	Phosphine	Methyl bromide
Formulation	tables, pellets, strips	liquid in cylinders
Application	easy	special equipment required
Diffusion	good	fair
Grain penetration	excellent	good
Min. temperature application	10°C	5°C
Time of exposure	5-8 days	12-24 to 48 hours
Residue	nil	possible
Phytotoxicity	nil	possible
Flammability	flammable under certain conditions.	non-flammable

iii. Application

It is worth noting again that fumigants are hazardous products highly toxic to humans; therefore only teams of skilled and properly trained operators should be allowed to carry out fumigations. Storekeepers should never carry out a fumigation; their role should only be to call in the Plant Protection Service concerned.

The requirement for achieving satisfactory results from a fumigation is good tightness of the enclosure to be fumigated. To fumigate the total volume of a store requires perfect tightness of the structure. As in developing countries such conditions can seldom be fulfilled regarding the warehouses, the most common method is to fumigate bag stacks under plastic sheets.

There are many types of plastic sheets of different size and thickness. Normal polythene sheets or nylon-reinforced and PVC or neoprene coated sheets can be used. Polythene sheets are generally 150 to 200-microns thick. In any case, the use of two superimposed sheets each 100-micron thick is preferred to only one 200-micron sheet. Regarding sheets that have already been used, they should be examined to detect any holes and/or tears which should be sealed with adhesive tape.

The sheets are laid on the top of the stack; they are joined together with a 1m-wide overlap, then rolled up and clipped.

The required quantity of phosphine should be determined previously according to the volume of produce to be fumigated. When using tablets, efforts should be made to use a quantity of commercial product equal to a whole number of tubes.

Assume, for instance, a 8m x 6m x 4m stack to be treated. What is the number of tablets required?

$$\text{Volume to be treated: } 8 \times 6 \times 4 = 192\text{m}^3$$

On a 2g/m³ basis, 384gr of PH₃ are required, each tablet contains 1gr of PH₃; 384 tablets are therefore necessary; as each tube contains 30 tablets, the required number of tubes will be:

$$\begin{array}{r} 384 \\ \hline 30 \\ \hline 12.8 \end{array} \text{ tubes}$$

That is, 13 tubes will, in practice, be used.

All empty tubes should be destroyed.

The tablets are placed, here and there, on the top and around the stack in small cups or trays (pieces of cardboard or paper) so as to allow easy recovery of fumigant residue (grey powder) at the end of the fumigation. As gas is not immediately released there is time enough (half an hour or more) to place the tablets and cover the stack by unrolling down the sheet (or sheets) from the top of the stack; sheets must hang down on the floor 65cm to 1m wide around the stack.

To obtain the required tightness, the sheet base on the floor should be covered with sand (an ideal practice, seldom possible) or with sand snakes filled with sand; to be easily handled, sand snakes should be about 10cm in diameter and 1m long, or less.

After the operation, the walls of the treated stack should be clearly marked with "danger of death" warning notices. After the time of exposure (at least 4 to 5 days), the building where the fumigation has been carried out should be entered with precautions and respirators should be used.

First of all the warehouse should be ventilated by opening doors and ventilation openings so as to maximize the airing of the space; the fumigation sheet is partially uncovered so as to let out the remaining gas; one hour later, the fumigation sheet can be entirely removed and the warehouse left open to ventilate for several hours before entering again.

Gas concentration can be checked at any time with gas detector tubes that allow gas concentrations ranging from 0.1 to 40 ppm to be detected. Phosphinometers or fumigameters (recently developed in France) can also be used for the purpose. The maximum concentration accepted for workers is 0.3 ppm for continuous exposure and 1 ppm for short exposure. The absence of odour does not mean that there is no gas since the lower limit of smell perception is 2.7 ppm.

The first symptoms of PH₃ poisoning are respiratory troubles, chest pains, nausea and vomiting. Any person experiencing such troubles should immediately be taken out from the toxic environment to the open air outside the store and, if necessary, to the nearest hospital; see that the person keeps quiet and never give alcohol or milk.

Fumigation residues (grey powder remaining on trays) should be recovered and destroyed as follows: they are poured into a bowl that contains water mixed with detergent (30-60gr of detergent per 10-25 l of water); the mixture is then stirred to dissolve the powder. As the resulting solution is not hazardous, it can be thrown away normally.

iv. Safety measures to be taken to apply fumigants

- All the operators involved in fumigation operations should be specifically trained (fumigation is a job for specialists only!).
- The team should consist of at least two operators (never act alone).
- They must be trained in first-aid.
- Workers that handle fumigants must wear gloves or wash their hands with soapy water after work.
- Respirators with appropriate canisters should be available.

- Equipment for gas detection should be available (detector tubes and appropriate pumps or phosphinometer).
- All packing (e.g. empty tubes) must be destroyed after using the fumigant.
- Fumigation residue should be destroyed.
- "Danger of death" warning notices must be posted on the fumigated places and buildings closed to the public.
- Address of the nearest doctor and hospital should be known.

Among the insect control methods considered above it is worth noting that fumigation allows a curative treatment of stored commodities by which all stages of insect life are killed. Nevertheless, as fumigants are not persistent, reinfestation remains possible after the treatment.

As far as treatments with contact insecticides are concerned they allow some lasting protection - new insecticides such as pirimiphos methyl have a persistence that can be up to 6 months - but do not kill the first stages of insect life i.e. eggs, larvae and pupae that can develop within individual grains; it is therefore recommended to combine both techniques (fumigation and contact insecticides).

B. CONTROL OF RODENTS

Rodents are important destructive pests of stored commodities. They will cause losses by consuming the stored produce and also by contaminating it through droppings and by damaging bags and storage structures. Curative methods of control always prove difficult to apply because they require a thorough knowledge of animal biology and the use of chemicals toxic to humans and domestic animals. In any case, it is always easier and cheaper to apply preventive methods, the most effective of which is good housekeeping inside and outside the store.

1. Main destructive rodents of stored produce

The main rodent that attack stored commodities belong to the muridae family. The most common species are represented by the roof or black rat (*Rattus rattus*), the brown or Norway rat (*Rattus norvegicus*) and the mouse (*Mus musculus*); they can be observed everywhere in the world. Some local species also attack stored produce, such as the mutlimamilatte rat of Africa (*Mastomys*). Table 5/5 gives the characteristics of the three main species illustrated in Figures 40, 41 and 42.

Table 5/5. Main destructive rodents of stored produce

NAME	RATTUS NORVEGICUS (brown rat)	RATIUS RATTUS (roof rat)	MUS MUSCULUS (mouse)
Mean weight	330gr	250gr	16gr
Tail	shorter than head + body	longer than head + body	longer than head + body
Ears	thick, opaque, with fine hair	thin, translucent, long, hairless	long with some hair
Muzzle	short	pointed	pointed
Colour	grey brown, sometimes black on the back and grey underneath	grey, black, brown or red, sometimes white underneath	variable, grey
Droppings	grouped, but sometimes scattered, ellipsoidal or slender	scattered, sausage- or banana-shaped	scattered, thin and slender
Habits	digs burrows, can climb, swings well, reacts to new objects, can live in sewers, does not like changes, rather conservative habits.	excellent climber, reacts to new objects, rather roving habits.	sometimes digs burrows, good climber, reacts little to new objects, rather roving habits.
Localization	lives only in ports and some in-land cities	can be found everywhere	in most towns of recent growth

2. Methods of rodent control

(a) Preventive methods of control

i. General remarks

Preventive methods mainly consist in creating an unfavourable environment, taking into account some biological characteristics of rodents.

- Rats are good climbers (especially the roof rat); they can climb rough walls but cannot climb smooth surfaces more than 30cm high.
- Rats cannot jump more than 30cm in height.
- They do not dig more than 40cm in depth.
- They cannot pass through a concrete layer more than 10cm thick.

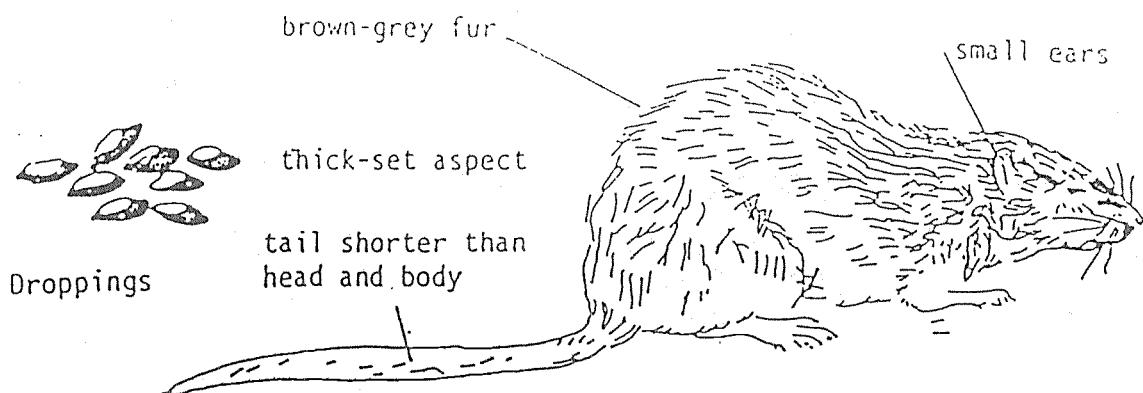


Figure 40: Norway rat

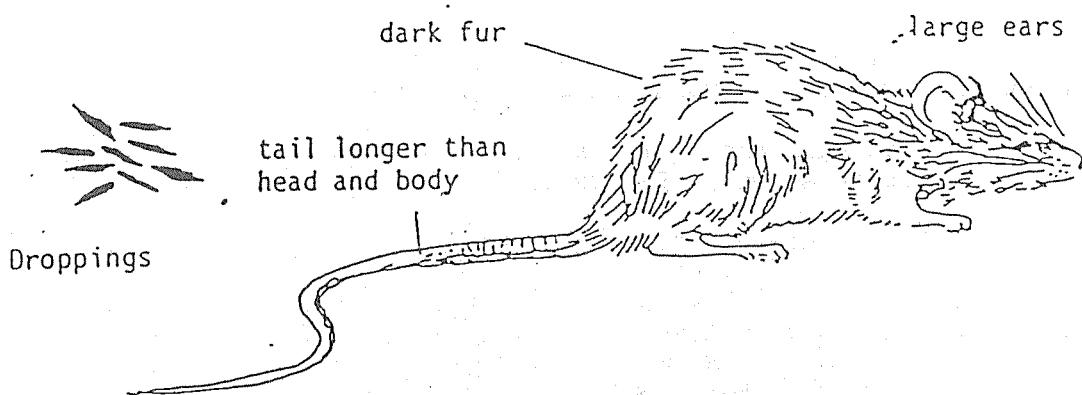


Figure 41: Roof rat



Figure 42: House mouse

- They cannot pass through wire mesh with openings less than 1cm.
- They attack lead, tin and plastic pipes.

Such observations allow storage structures to be equipped with effective rat-guard barriers.

ii. Protective measures at the building level

Doors, ventilation openings and gaps between the roof and the walls constitute for rodents the main sources of entry into storage buildings; they essentially gain access to stores through down-pipes and connecting cables.

- Doors

As metal double-hinged doors close tightly, they provide good protection from rodents. If they are of timber, the outside face should be covered with a sheet metal as illustrated in Figure 22. For sliding doors a rodent-proof system is proposed in Chapter 4 and shown in Figure 21.

- Ventilation openings should be screened with 6 to 10mm wire mesh or wire netting.
- Connecting cables and down pipes should be equipped with steel flanges or conical ratguards made of metal sheets.
- Gaps between the walls and the roofing sheets should be closed with concrete as shown in Figure 18.

iii. Store hygiene, inside and outside

Rats have a predilection for rubbish and refuse heaps; they are timid and avoid open spaces. They shelter behind any accumulation of materials they can find in the vicinity of stores (e.g. scrap heaps, bushes) and their routes typically follow all things left unused outside and/or inside of the stores (old tyres, piles of old bags, cans, boards).

Therefore, as preventive method of control, all rubbish and refuse likely to constitute harbourage for rodents should be removed and storage areas should be kept perfectly clean; the store surroundings should be clear and a wide area should permanently be kept perfectly clean with all possible unused materials removed and bushes and weeds cut.

Preventive methods of control are easy to apply and generally not very expensive because major works are not needed. They should always be observed with rigorous care.

(b) Active control

This includes the biological, physical and chemical control.

- Biological control mainly consists in protecting rodent predators such as birds of prey, reptiles and small carnivorous animals whether they are domestic (cats) or wild (e.g. foxes, jackals).

ii. Physical controls includes:

- Traps: the method does not prove very effective but allows individuals to be captured making it possible to identify the rodent species attacking the produce.

- Ultrasonic emission or modification of the magnetic fields to which rodents are sensitive. The results of such methods are still much debated.

iii. Chemical control consists in giving to rodents chemicals, called rodenticides, in a bait form. Rodenticides are available either as acute poisons that cause sudden death immediately after first ingestion or as anticoagulant poisons, the action of which is gradual and does not induce rejection by rodents.

- Acute poisons

These chemicals are very hazardous to humans and domestic animals and baits should be prepared by rodent control specialists. Arsenious oxide, zinc phosphide, sodium fluoracetate (1080), thallium sulphate, scilliroside and Antu are the most common poisons. As these chemicals are highly toxic, their use is always doubtful in buildings where food commodities are stored; some acute poisons are even forbidden in several countries. Their major disadvantage is that, as some individuals in the rodent colony are killed by sudden death, the remainder will become suspicious of the poisoned bait and cease consuming it. Furthermore, the technique is not always efficient because repeated use of the same rodenticide may lead to some rodents becoming resistant. At the present time, anticoagulant poisons are mainly used.

- Anticoagulant poisons

Coumafene, chlorophacinone, difenacoum, bromadiolone and other anticoagulant rodenticides are presently available. Due to the weakness of their circulatory system, rodents die from internal hemorrhages when they ingest anticoagulant rodenticides. As death occurs some days after consuming the bait, the other rodents do not become suspicious. The dose of rodenticide chemical to be mixed with the bait (grain) is 0.025 percent for coumafene and 0.005 percent for chlorophacinone; modern anticoagulant rodenticides such as difenacoum and bromadiolone are used at 0.005 percent; they are of interest because they present little danger to humans and domestic animals (except maybe to pigs).

- Baiting

Rodenticides are given to rodents in baits which must be carefully placed if they are to be eaten. Baits, with which rodenticides are mixed, must be attractive to rodents.

- Grain will be preferred to flour.

- Humid baits prove more attractive in dry climates.

- Bait will be made more appetising by using the following ingredients:

salts.....	4 gr/kg
caster sugar.....	50gr/kg
vegetable oils.....	50cm3/kg
liquid paraffin.....	30-50cm3/kg
peanut butter.....	20-30gr/kg

Bait placing: baits should be placed on the route of rodents between their nesting site and the stored produce, as close as possible to the nesting site; they should not be placed in the open because rats prefer to eat in hidden places; baits should not be accessible to domestic animals (e.g. hens and chickens). Figure 43 shows some types of baiting sites.

The following procedure can be applied for placing baits:

1st day : 60gr - baits placed at chosen points;

3rd day : Inspection of every baiting point; for baits totally consumed, increase the bait weight to 120gr; for baits partially consumed replenish up to 60 grammes;

5th day : Inspection of every baiting point, as on 3rd day; increase the bait to 240 grammes; remove all dead rodents;

8th day : Inspection of every baiting point; where baits have been consumed, proceed as indicated above.

10th day : Remove the baits unless there is some risk of re-infestation.

To avoid or prevent any resistance developing, it can be useful, after treatment with anticoagulant for instance, to apply another treatment of the non-habit-forming type. There are also the so-called tracking powders (e.g. Antu) which are laid along the routes followed by rodents so that they pick up the powder in their fur and ingest it during grooming; nevertheless this technique may be dangerous because rats can also leave the poison on foodstuffs as they come into contact with them.

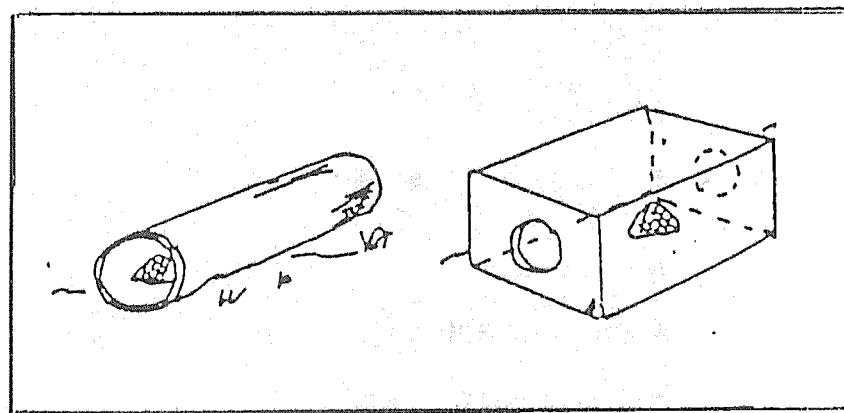
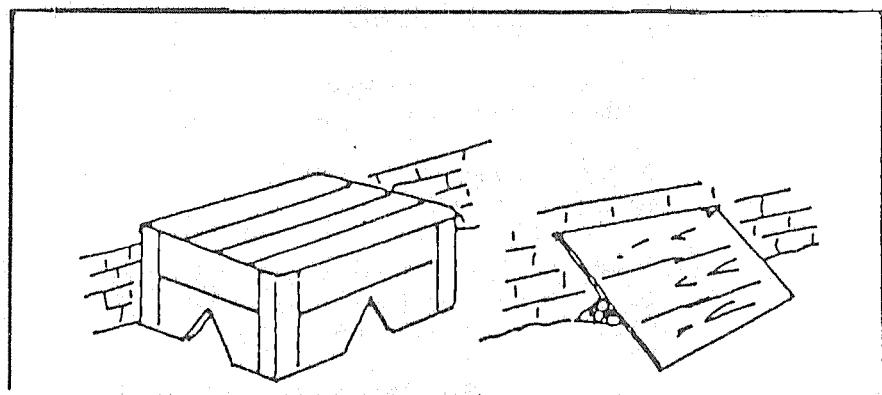


Figure 43: Bait containers

ANNEX I

GLOSSARY OF TECHNICAL TERMS

- "Banco" : A traditionally used building material consisting of a clay mortar mixed with straw.
- Blocks : Prefabricated rectangular elements of construction, made of concrete, and sometimes hollow.
- Caryopsis : A one-seeded dry fruit with the pericarp closely adhering to the seed.
- Coleoptera : Order of insects distinguished by an anterior pair of sclerotized rigid wings (elytra that protect the posterior membranous wings).
- Cow pea : A small-seeded legume mainly grown in dry areas.
- Damp-proof : That resists moisture, prevents damp from passing through.
- Dusting : Type of treatment that consists in applying insecticide dusts to products to be stored.
- Endosperm : A nutritive tissue in seeds, formed around the embryo and absorbed by it during development.
- Enzyme : Organic soluble substance that promotes or hastens a reaction. Enzymes are complex proteinaceous molecules acting as catalysts of biochemical reactions.
- Fogging : A type of treatment that consists in applying pesticides as a fog.
- Fumigant : A substance that, at a given temperature and pressure can be produced in a gaseous form at a lethal concentration for a given living species.
- Gable end : The triangular upper part of the end wall on which rest the purlins of a double-pitched roof.
- Hygrometry : Measurement of the moisture content of the air.
- Hygroscopic : Capable of absorbing the water vapour contained in air. When the hygroscopic equilibrium - also called Equilibrium Moisture content, EMC - is reached, this means the partial pressure of water vapour on the surface of the produce is equal to the partial pressure of water vapour in the ambient air; there is no more exchange of water vapour between the produce (e.g. grain) and the ambient air.

- Insecticide : A substance having the property to kill insects; it is used to control insect pests.
- Larva : An active form, quite different from the adult, of some animals resulting from the egg stage. Insect larvae are the main agents causing damage to stored commodities.
- Lepidoptera : Order of insects commonly known as butterflies or moths, with two pairs of membranous wings covered with coloured scales.
- Metabolism : Biochemical reactions that occur within living matter and by which certain substances develop (anabolism) or break down and release energy (catabolism).
- Microflora : Microscopical plants living in grain or other products (e.g. moulds, yeast).
- Moisture content : Expresses, in percent, the ratio of the mass of water contained in a sample of grain to the total mass of the sample.
- Moulds : Common name of small fungi which cause chemical breakdown of the agricultural produce and food they live on.
- Mycotoxin : Toxic substance produced by moulds (e.g. Aflatoxin produced by Aspergillus Flavus).
- Organoleptic : Relating to the property of making a direct impression upon the sense organs; flavour, odour, appearance, texture, colour of a substance.
- Pericarp : The aggregate of tissues (epicarp, mesocarp, endocarp) around a fruit seed.
- Pest : An organism that causes damage to foodstuffs, mainly by feeding on them.
- Purlins : Horizontal elements of construction in a roof framework, which support the rafters.
- Pyrethrin : An organic substance; insecticide extracted from pyrethrum flowers; synthetic pyrethrins also exist.
- Ring beam : An element of construction used to reinforce masonry walls.
- Rodenticide : A product for killing rodents.
- Span : The distance between two posts or supports; also the spacing between two successive trusses in a roof framework.

- Spraying : A type of treatment consisting in applying liquid insecticides in the form of small droplets.
- Thermometric : Relating to the measurement of temperature (e.g. a thermometric spear).
- Treatment : An operation that consists in applying or implementing one or several physical, chemical or biological agents so as to protect or increase agricultural production.
- Truss : A triangular element of framework arranged vertically to support a roof covering; the several trusses which form the roof frame are joined together by purlins.

ANNEX II

TEMPERATURE AND MOISTURE CONTENT MEASUREMENT

The measurement of the two major factors of spoilage of stored produce, i.e. moisture content and temperature, is essential to rationally and efficiently managed storage.

A. MOISTURE CONTENT MEASUREMENT

1. Grain moisture content measurement

(a) The moisture content (mc) of produce is commonly expressed as the ratio (in percent) of the weight of water contained in the produce to the total weight of the sample:

$$\% \text{ m.c.} = \frac{\text{weight of water}}{\text{total weight}} \times 100$$

(b) Measurement principles

The devices available for determining moisture content measure physical properties closely related to moisture content, such as:

- loss in weight;
- grain conductivity and dielectric constant;
- relative humidity of the air in equilibrium with the produce.

(c) Methods

"Practical" method of reference

A 5gr sample of ground produce is placed in a drying-oven at 130°C; after 2 or 4 hours (for maize), the produce is removed from the oven and placed in a container with a desiccant (silica gel) and left to cool for 4 hours; the sample is then re-weighed.

Moisture content is calculated as follows:

$$\% \text{ m.c.} = \frac{\text{weight of wet produce} - \text{weight of the dry produce}}{\text{weight of the wet produce}} \times 100$$

Example: if after drying, the 5gr sample only weights 4.4gr, the moisture content is:

$$\frac{5 - 4.4}{5} \times 100 = 12\% \text{ m.c.}$$

Grain dehydration is frequently carried out in a Chopin multi-cellular oven (or slow drying oven).

Oven-drying is a very accurate method (0.3% and even less) for determining moisture content, but it is slow and requires sophisticated instrumentation.

Practical methods of possible use in warehouses

Dessication

- Rapid oven-drying (Chopin type)

A sample of some grammes (5 to 10gr) is placed in a small electrical oven to dry at 160°C-200°C. Moisture evaporates through a calcium carbide cartridge with which it reacts and generates acetylene that is burnt at the level of a burner. A special burner provided with the appropriate mask should be employed for each different product. When the flame is totally obscured by the mask the process can be considered as finished. The complete extinguishing of the flame should not be reached because this will result in an overvalued moisture content. The bowl containing the sample is removed and left to cool before re-weighing on a scale specific to the oven; the beam of the scale is directly graduated in percent moisture content.

For good results, weighing should be highly precise. The temperature in the oven should be stable; calcium carbide should frequently be renewed (every third measurement).

The oven-drying instruments offer the advantage of being reliable regardless of the moisture content of the produce to be measured; nevertheless they also present several disadvantages:

- Samples must be carefully prepared (*) and accurately weighed;
- samples are very small (5 to 10gr) and several measurements are required to allow an accurate idea of the mean moisture content of a batch;
- the equipment is fragile and is dependent on an electricity supply;
- reading is not immediately obtained (delay of 10 to 15 mn);
- complex use that requires skilled personnel.

(*) Depending on the produce involved, whole grains should be used (e.g. paddy, sorghum, millet, wheat) or grains should be divided into 2 or 4 (e.g. maize, peanut, beans, coffee).

Nevertheless in a storage centre such equipment is absolutely necessary to calibrate, on a comparative basis, the various moisture meters used in the warehouses.

- The infrared lamp (Infra-Tester).

A ground sample is placed on a balance pan and exposed to the intense heat of an infrared lamp; as water evaporates, the balance pan moves up, which is counterbalanced by sliding a pointer along a scale graduated in percent moisture content. Results obtained with this type of equipment are usually lower than the real moisture content because produce tends to reach equilibrium with the relative humidity of the ambient air and always retains some water.

Measurement of electrical properties of the grain

Electrical moisture meters can measure either the resistivity of the grain to the passage of a steady current, or the dielectric constant of the grain in a capacitor receiving high-frequency alternating current.

- The instrument for measuring the electric resistivity of the grain consist of an ammeter calibrated in moisture content that measures current intensity after passing through the bow that contains the sample.

Such instruments are often small portable battery-powered devices; this constitutes their main advantage. Furthermore they are not expensive. They can be directly read but are not very reliable. Readings may vary depending on the grain variety and also on the grain shape. Some instruments require ground grains which limits their use to produce with moisture content below 18 percent.

Due to the low reliability of this equipment, it is not recommended for warehouses as the moisture content of stored produce should be determined with accuracy if safe storage is to be obtained; on the other hand, it can be useful to farmers, allowing them to evaluate the moisture content of the crop and so to conveniently schedule harvesting.

- Instruments measuring the dielectric constant of grains.

Moisture meters comprise two relatively high-frequency (2400 hertz) alternating current circuits. Two capacitors, i.e. a fixed capacitor and a variable one, are wired in series in one of the circuits; the fixed capacitor constitutes the measuring chamber with the grain acting as insulator. The introduction of grain generates a modification in current frequency. Equilibrium is reached again with the frequency of the reference capacitor by acting on the variable capacitor; the capacitor spindle is provided with an indicator which, after calibration, allows a direct reading of the moisture content on a dial.

Moisture meters are supplied with specific calibration curves for each product. As the properties measured may vary depending on the grain shape and size, it may be necessary to use different calibration curves corresponding to the varieties involved (when purchasing a

moisture meter it is useful to provide the manufacturer with a maximum of data relating to the produce to be tested, so that he can supply a properly calibrated instrument).

With moisture meters measuring the dielectric constant, relatively large quantities (100 to 400gr) of whole grain are generally used, which allows good representativity of the batch; nevertheless, measurements can be affected by the following factors:

- Temperature of the sample.
- Degree of compaction and weight of the sample.
- Degree of cleanliness of the sample.
- Water distribution within the grain.

Temperature:

Moisture meters are calibrated at 20°C. When the sample temperature is lower or higher, a reading correction of about 0.1 percent should be made for every degree below or above 20°C. Furthermore, as the reading can be properly used only if the sample and the device have the same temperature, it is necessary - as far as possible - to "use the device in a place where the temperature is the same as where the produce is being stored"; corrections to be made are described in the instructional leaflet supplied with each instrument.

Degree of compaction and weight of the sample:

All measurement should be made on a fixed volume of constant density. As moisture meters are sensitive to compaction, vibrations should be avoided during measurements and the grain should be poured evenly and gently into the measuring chamber.

Cleanliness of the sample:

Moisture meters are calibrated exclusively with samples consisting of clean whole grain, but in practice any batch of grain contains foreign matter and broken grains, which affect the readings:

Apparent moisture content increases by 1.5 to 10 percent for 2 percent of foreign matter.

A 1 to 4 percent increase in apparent moisture content can also be observed with 6 percent of broken grain.

Water distribution within the grain:

Electrical devices using whole grain measure properties at the grain periphery; therefore water should necessarily be in equilibrium in all parts of the grain to allow the measurement to be accurate. Immediately after drying, as the peripheral part of the grain is drier than the inside, any measurement will be low if a period (10 hours approximately) has not been allowed for the moisture to distribute evenly; on the other hand, when the grain temperature is lower than ambient air, the air moisture will condense on grains and measurements will be high.

The moisture content of recently dried grain or/and superficially wet grain can be measured with accuracy but only after a 10-hour period.

It should be recalled that such equipment must be properly maintained and regularly checked and re-calibrated if necessary; it must also be noted that any sample can only be used once, because its electric properties will be modified during the measurement.

In spite of such disadvantages, electrical instruments are largely used because they also offer many substantial advantages. They are easy to use and allow immediate results from a sample of various hundred grammes in weight that will be representative of the whole batch providing that sampling has properly been made. There are many moisture meters based on the measurement of the dielectric properties of grain.

Nevertheless they are rather sophisticated and expensive.

Moisture meters measuring the relative humidity of the air in equilibrium with the produce

In Chapter 2 it has been noted that intergranular air comes into equilibrium with the moisture content of the produce.

For measuring, the spear is introduced into the produce to be tested and left there until equilibrium is reached, which may take some 10 minutes; such devices are not very accurate.

Due to the time required for measuring, these devices are not much used at trade level but are useful as control means at the level of bulk and bag storage. Commodities are generally stored at 70 percent relative humidity, which corresponds to the limit for preventing mould from developing. Spears are not used for measuring but for checking that storage conditions are safe.

As a conclusion to the discussion on the various methods applied for measuring moisture content, we should emphasise the necessity, for each user, of selecting among the many devices available on the market, the right one specifically adapted to his needs; he should give to the supplier precise information on the produce to be tested, its variety (giving a sample if necessary), indicate the range of moisture content the device will be used for and also the conditions and frequency of use.

As knowing the moisture of the crop is a requirement for safe storage, any storage centre (bulk or bag storage) should therefore be provided with efficient instruments for measuring this factor. Electrical moisture-meters (based upon the measurement of dielectric properties) which allow a direct reading of moisture content, should be available in each centre. Equipment of the drying oven type (e.g. the Chopin rapid oven) will allow regular checking of the results. Small portable devices (resistivity measurement), easy to use (Dickey John type) should also prove very useful at the farmers' level.

It is therefore desirable, and even necessary, that in the future moisture meters come into general use.

2. Air moisture measurement

(a) Relative humidity of air

Relative humidity (RH) is the ratio of the actual water vapour pressure (Pw) to the vapour pressure of saturated air at the same temperature (Pw sat):

$$RH \% = \frac{P_w}{P_w \text{ sat}} \times 100$$

It can also be defined as the ratio of the weight of water vapour contained in 1kg of air to the maximum weight of water vapour that 1kg of air can contain when it is saturated at a given temperature.

$$RH \% = \frac{\text{Weight of water vapour in } 1\text{kg of air}}{\text{Weight of water vapour in } 1\text{kg of saturated air}} \times 100$$

Air is saturated when it cannot absorb more water, its relative humidity being 100 percent. The maximum quantity of water vapour that the air can contain varies greatly with its temperature as shown in Table A.2/1.

Table A.2/1. Weight of water vapour contained in 1kg of dry air at different temperatures

Air temperature ($^{\circ}\text{C}$)	0	10	20	30	40
Max. weight of water vapour (gr)	3.9	7.9	15.2	28.1	50.6
Air temperature ($^{\circ}\text{C}$)	50	60	70	80	90
Max weight of water vapour (gr)	89.5	158.5	289.5	580.0	1559

Example: with air at 40°C containing 25.3gr of water vapour per kilogramme, relative humidity will be:

$$\frac{25.3 \times 100}{50.6} = 50\% \text{ RH}$$

Application 1: with air also containing 25.3gr of water vapour kilogramme, but at 30°C , relative humidity will be:

$$\frac{25.3 \times 100}{28.1} = 90\% \text{ RH}$$

Application 2: with air at 60°C and 40% RH, the weight of water vapour (m) per kilogramme of air will be:

$$m = \frac{158.5 \times 40}{100} = 63.4\text{gr}$$

(b) Relative humidity measurement

Conventional hygrometers can be used to measure the relative humidity of air. Small portable devices known as thermo-hygrometers are also available; they are easy to use, battery-powered and allow the air temperature and relative humidity to be measured.

The most rudimentary method consists in reading the dry- and wet-bulb temperatures from a psychrometer. The device consists of two conventional mercury-in-glass thermometers, one of which has a moistened cotton pad or muslin on the bulb; this one gives the so-called wet-bulb temperature. Psychrometers should be placed in a draught (air movement being necessary) as shown in Figure 44.

From the wet- and dry-bulb readings, the relative humidity of the air can immediately be found by using a psychrometric chart or simply by using tables such as Table A.2/2 for instance.

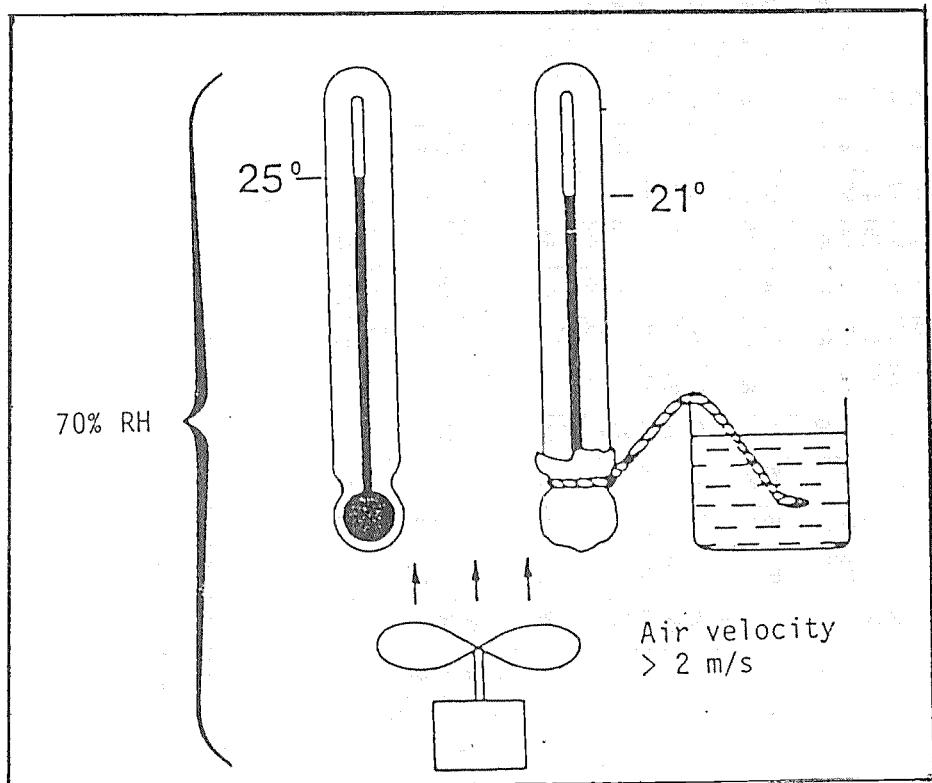


Figure: 44

Psychrometer

Table A.2/2 Relative humidity deduced from dry-bulb and wet-bulb temperature

$t-t'$	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,5	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10,0	10,5	11,0	11,5	12,0	12,5	13,0	13,5	14,0
t	90	85	81	76	71	67	63	58	54	50	46	42	38	34	30	26	23	19	15	12	8	5						
16	95	90	86	81	76	72	68	64	60	55	51	47	43	40	36	32	28	25	21	18	14	11	8	5				
17	95	90	86	82	77	73	69	65	61	57	53	49	45	41	38	34	30	27	23	20	17	14	11	8	5			
18	95	91	87	82	78	74	70	65	62	58	54	50	46	43	39	36	32	29	26	24	21	19	17	14	11	8	5	
19	95	91	87	83	78	74	70	66	63	59	55	51	48	44	41	37	34	31	29	26	23	21	18	16	13	10	6	
20	95	91	87	83	78	74	70	66	63	59	55	51	48	44	41	37	34	31	29	26	23	21	18	16	13	10	6	
21	96	91	87	83	79	75	71	67	64	60	56	53	49	46	42	39	36	32	29	27	25	22	20	18	16	13	10	
22	96	92	88	84	80	76	72	69	65	62	58	55	52	49	45	42	39	36	33	31	28	26	24	22	20	18	16	6
23	96	92	88	84	80	77	73	69	66	62	59	56	53	49	46	43	40	37	34	31	29	27	25	23	21	19	17	14
24	96	92	88	84	80	77	73	70	67	63	60	57	54	50	47	44	41	39	36	33	31	29	27	25	23	21	19	17
25	96	92	88	84	81	77	72	70	67	64	61	58	54	51	49	46	43	40	37	34	32	30	28	26	24	22	20	18
26	96	92	88	85	81	78	74	71	67	64	61	58	56	53	50	47	44	41	39	36	34	32	30	28	26	24	22	20
27	96	92	89	85	82	78	75	71	68	65	62	59	56	53	50	47	44	41	39	36	34	32	30	28	26	24	22	20
28	96	92	89	85	82	78	75	72	69	65	62	59	56	53	50	47	44	41	39	36	34	32	30	28	26	24	22	20
29	96	93	89	86	82	79	76	72	69	66	63	60	57	54	52	50	47	44	41	39	36	34	32	30	28	26	24	22
30	96	93	90	86	83	79	76	73	70	67	64	61	58	55	52	50	47	44	41	39	36	34	32	30	28	26	24	22
31	96	93	90	86	83	80	77	73	70	67	64	61	59	56	53	50	48	45	43	40	38	35	33	31	29	27	25	22
32	96	93	90	86	83	80	77	74	71	68	65	62	59	56	53	50	48	45	43	40	38	35	33	31	29	27	25	22
33	97	93	90	87	83	80	77	74	71	68	66	63	60	57	55	52	50	47	45	42	39	36	34	32	30	28	26	24
34	97	93	90	87	84	81	78	75	72	69	66	63	61	58	56	53	50	48	45	42	39	36	34	32	30	28	26	24
35	97	94	90	87	84	81	78	75	72	69	67	64	61	59	56	54	51	49	47	44	41	39	36	34	32	30	28	26
36	97	94	90	87	84	81	78	75	72	69	67	64	62	59	57	54	51	49	47	44	41	39	36	34	32	30	28	26
37	97	94	91	87	84	82	79	76	73	70	68	65	63	60	58	55	53	51	49	47	44	41	39	36	34	32	30	28
38	97	94	91	88	84	82	79	76	74	71	69	66	63	61	58	56	54	51	49	47	44	41	39	36	34	32	30	28
39	97	94	91	88	85	82	79	77	74	71	69	66	64	61	59	57	54	52	50	48	46	44	42	39	36	34	32	30
40	97	94	91	88	85	82	79	77	74	72	69	67	64	62	59	57	54	51	49	47	44	42	39	36	34	32	30	28

t = dry-bulb temperature
 t' = wet-bulb temperature

Temperatures read from the psychrometer
 Examples: dry-bulb temperature $t = 25^{\circ}\text{C}$
 Wet-bulb temperature $t' = 21^{\circ}\text{C}$

Difference in temperature = 4°C
 Therefore, the relative humidity of the air is 70%.

B. TEMPERATURE MEASUREMENT

Checking the temperature in stored commodities is fundamental to follow the behaviour of produce during storage. A slow rise in temperature may result from a temperature increase in the outside atmosphere, but this frequently means the beginning of deterioration that should immediately be controlled. Temperature should frequently be checked during storage.

Liquid expansion thermometers are the most commonly used in bag storage centres.

Such thermometers measure the expansion/contraction of a liquid (mercury or alcohol) induced by a change in temperature. They are incorporated in metal probes and allow the temperature within moderate depths in bags and bulk grain to be measured. Tubes can also be placed vertically or inclined within the mass of grain so as to allow for a thermometer tied to a thread, to be introduced down the tube; but the presence of a tube causes errors resulting from the so-called "chimney effect" and also from its location between the grain and the thermometer. Furthermore, the movement of the thermometer from the measurement point to the point of reading also leads to erroneous readings, whatever the inertia of thermometer.

Many thermometric spears are now available; they are not very expensive and are easy to use.

ANNEX III

MAIN INSECTS OF STORED COMMODITIES

A. GENERAL REMARKS

During their development, insects pass through several stages;

egg --> larva --> pupa --> adult (or imag).

For most insects the life cycle is approximately 3 weeks to 1 month under favourable conditions, the optimum temperature for their development is between 25°C and 30°C (commonly found in hot climates). A lowering in temperature may greatly prolong the life cycle (e.g. up to 5-7 months at 15°C). Below 10°C and above 35°C the cycle ceases and insect mortality becomes very high; insect development also depends on the grain moisture content. Other important factors should also be considered, e.g. oxygen concentration, nature of the commodity, its texture (grain or flour), and density of population.

The main insect pests found in stored commodities belong essentially to the orders Coleoptera and Lepidoptera.

Coleoptera

Coleoptera of stored commodities are small in size and often difficult for non-specialists to identify. Their presence in warehouses is not immediately apparent because they shun light. Some species with a so-called "hidden form" live part of their cycle (larva and pupa stages) within the grain. Such is the case of weevils (*Sitophilus spp*), lesser grain borer (*Rhizopertha dominica*), and larger grain borer (*Prostephanus truncatus*) for cereals, and of pulse beetles for legumes. For the other species, the whole life cycle develops outside the grain. Such is especially the case of Khapra beetle (*Trogoderma granarium*), flour beetles (*Tribolium spp*) and saw-toothed grain beetle (*Oryzaephilus surinamensis*).

Lepidoptera

They are commonly known as "moths". They are relatively fragile and generally infest only the surface of stored commodities. Adult life is very short and only larvae are the major cause of damage as they feed on the grain and downgrade the commodities through the webs they weave. Some larvae develop inside the grain, e.g. Angoumois grain moth (*Sitotroga cerealella*) which can infest maize and sorghum in the field. For other moth (*Ephestia spp*), the larva is free and moves between the grains.

1. SITOPHILUS spp.

COMMON NAME: Weevil, Charançon, Gorgojo

ORDER: Coleoptera

SPECIES: In hot climates, *Sitophilus oryzae* and *Sitophilus zeamais* are mainly found.

IDENTIFICATION: Adults are 2.5mm - 4.5mm long, coloured dark brown, with the head prolonged by a long snout (rostrum) that allows them to be distinguished easily; rice weevil and maize weevil have four large reddish spots on the anterior wings (elytra). Larvae are globulous and have no legs.

BIOLOGY: Females lay their eggs within the grain, in holes they made with their snout; larvae pupate and develop, eating out the interior of the grain; after the pupa stage, adults bite their way out through holes.

DEVELOPMENT: Optimum in 26-30 days at 30°C and 70% m.c.

Limits: temperatures between 14°C and 34°C
grain moisture content above 11%

COMMODITIES CONCERNED: maize, rice, sorghum, wheat; grains are entirely eaten out.

2. RHIZOPERTHA DOMINICA

COMMON NAME: Lesser Grain borer, Capucin des grains, Capucino de los granos.

ORDER: Coleoptera

IDENTIFICATION: Adults are dark brown coloured, 2.5-3mm long and cylindrical; the head is hidden under the prothorax. Larvae have legs and resemble C-shaped grubs (scarablike larvae).

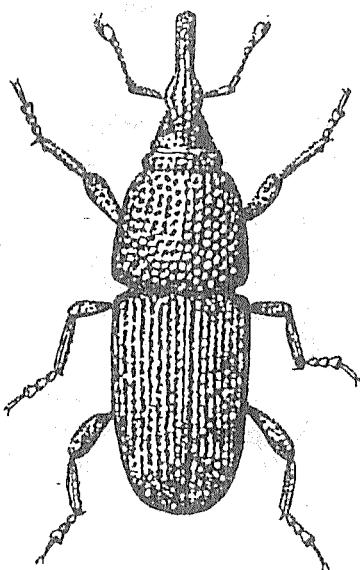
BIOLOGY: Larvae are very agile and penetrate into the grain previously attacked by adults. Adults are the major cause of damage as they attack the germ and the endosperm which they reduce to flour and leave only small fragments of integument.

DEVELOPMENT: Optimum in 25 days in 35°C temperature and 70% moisture content.

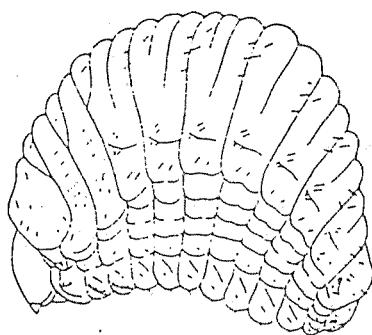
Limits: Temperature between 21°C and 30°C;
grain moisture content above 9%.

Lesser grain borer is well adapted to high temperatures and can develop in dry grain (9%)

COMMODITIES CONCERNED: Many cereals such as maize, sorghum and rice; also tubers such as cassava and sweet potato.



Adult



Larva

Figure 45: *Sitophilus oryzae*

3. PROSTEPHANUS TRUNCATUS

COMMON NAME: Larger grain bore, Grand capucin des grains.

ORDER: Coleoptera

IDENTIFICATION: This insect resembles the lesser grain borer, but is longer in size i.e. 3-5mm; its rectangular abdomen makes it distinguishable from *Rhyzopertha*.

BIOLOGY: Larger grain borers seem to attack primarily maize cobs stored at farm level. They cause high damage by reducing grains to flour.

Widely distributed throughout Central America, and beginning to infest East and West Africa (Tanzania and Togo respectively).

DEVELOPMENT: Optimum at 32°C temperature and 70% RH.

Limits: Temperatures between 18°C and 37°C.

Relative humidity above 40%.

COMMODITIES CONCERNED: Mainly maize; also dry cassava.

4. PULSE BEETLES

ORDER: Coleoptera

SPECIES: *Callosobruchus* spp - *Acanthoscelides obtectus*,
Bruchus spp - *Careydon serratus*.

IDENTIFICATION: Stout-bodies small insects (2-7mm) with a fine head and globulous eyes; larvae are 0.6-3mm long; they develop within the grain either in the field as the seed is developing or within stored grain. Several larvae can infest one seed. Adults leave the grain through perfectly circular holes.

BIOLOGY: Pulse beetles infest standing crops; some species have become adapted to stored commodities where they can proliferate in successive generations. Such pests are frequently specific to a crop, e.g. *Acanthoscelides obtectus* is specific to bean, *Callosobruchus maculatus* to cowpea, *Careydon serratus* to peanut. Only larvae cause damage.

DEVELOPMENT: Optimum in 30 days at 30°C temperature and 70% relative humidity.

COMMODITIES CONCERNED: Legumes (beans, cowpea, peas, peanuts, etc.). Only soyabean seems not to be attacked.

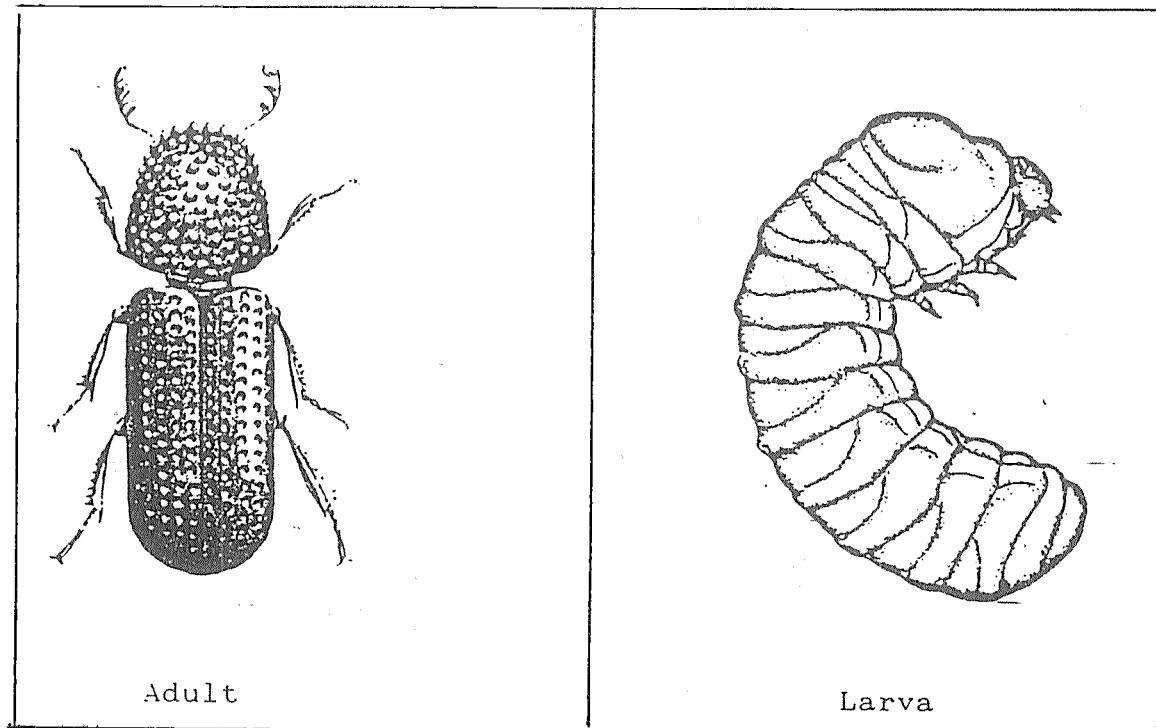


Figure 46: *Rhizopertha dominica*

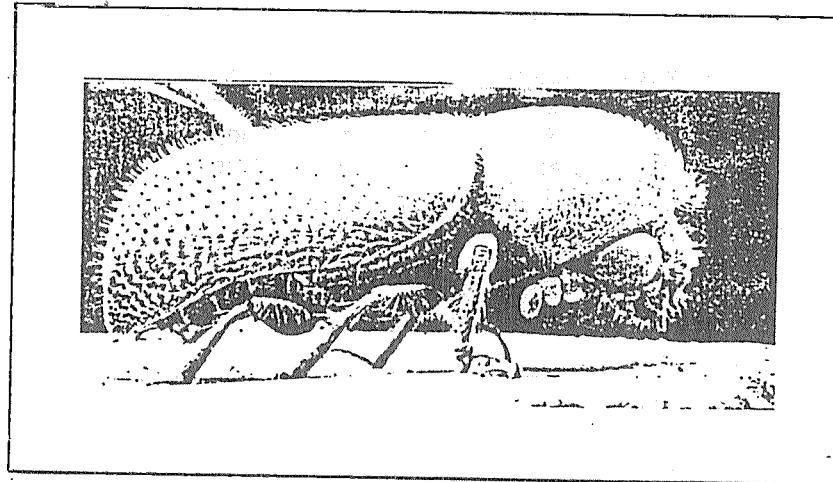


Figure 47: *Prostephanus truncatus*

5. TROGODERMA GRANARIUM

COMMON NAME: Khapra beetle, Trogoderme, Trogoderma del grano.

ORDER: Coleoptera.

IDENTIFICATION: Adults are oviform, 2 to 3.5mm long, red-brown coloured; the prothorax is V-shaped near the elytra. Infestation by Khapra beetle is easily detected because larvae have long bristles that allow them to be distinguished; larvae are 3 to 6mm long and reddish.

BIOLOGY: As adults do not feed, only larvae cause damage, they entirely eat out the interior of the grains. In warehouses larvae often concentrate in ears. Khapra beetle can resist drought and develop within very dry grain.

DEVELOPMENT: Optimum in 24 days at 35°C temperature and 70% relative humidity.

Limits: temperatures between 22°C and 42°C.

Relative humidity between 2% and 73%.

COMMODITIES CONCERNED: Cereals, legumes, peanuts, groundnut cake, etc.

6. TRIBOLIUM SPP

COMMON NAME: Flour beetle, Tribolium, Falso gorgojo de la harina

ORDER: Coleoptera

SPECIES: *Tribolium castaneum*, *Tribolium confusum*.

IDENTIFICATION: Small insects, 3 to 4mm long, brown coloured; adults are flat and elongated; larvae are vermiform, soft with small bristles and have two small pointed ends.

BIOLOGY: Adults and larvae attack commodities previously damaged by other insects (e.g. weevils). They feed mainly on broken grain. They downgrade the produce by nauseous secretions resulting in a musty taste and smell; they are well adapted to drought.

DEVELOPMENT: Optimum in 20 days at 35°C temperature and 70% relative humidity.

Limits: temperatures between 20°C and 40°C.

Relative humidity above 10%.

COMMODITIES CONCERNED: Broken cereals, flours and dry commodities.

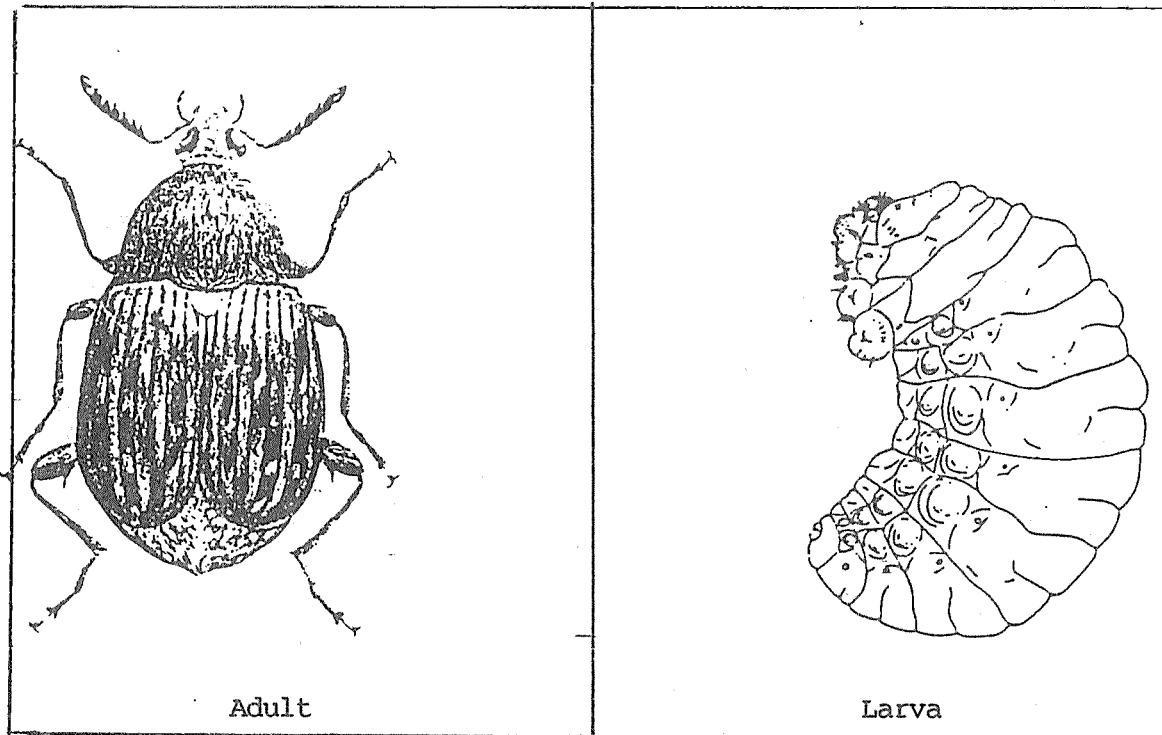


Figure 48: Dried bean beetle (*Acanthoscelides obtectus*)

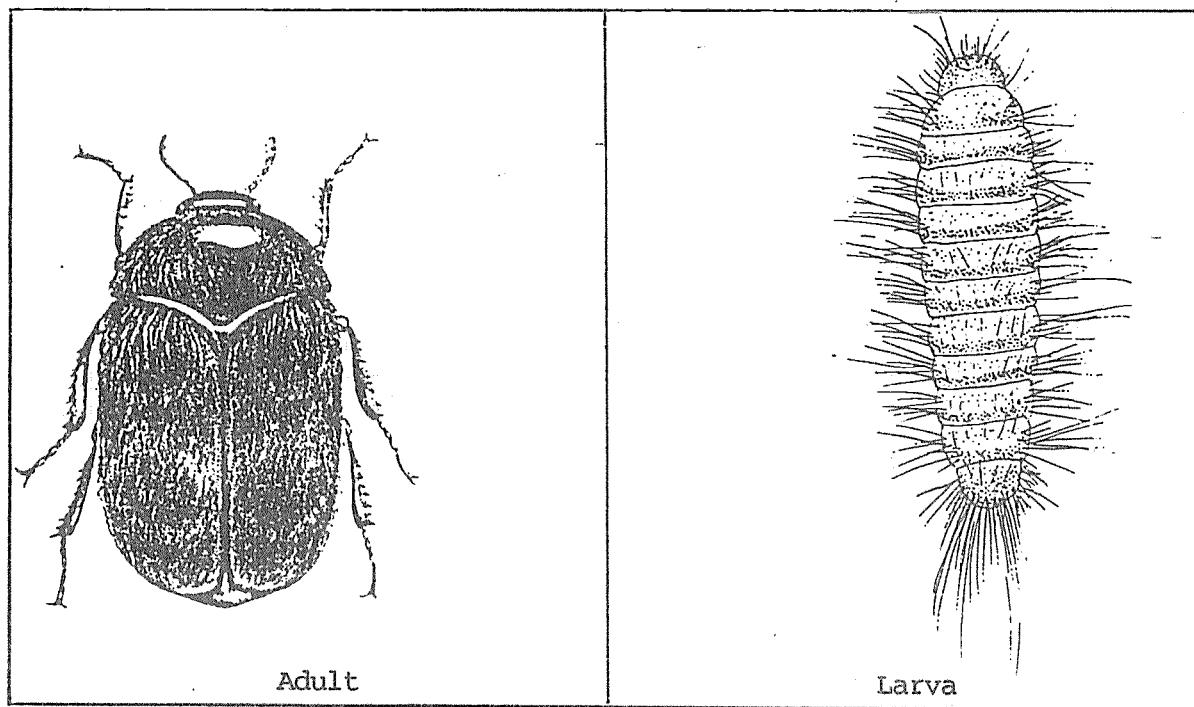


Figure 49: *Trogoderma granarium*

7. ORYZAEPHILUS SURINAMENSIS

COMMON NAME: Saw-toothed grain beetle, Silvain, Carcoma dentada.

ORDER: Coleoptera

IDENTIFICATION: Flat, elongated and 2.5 to 3.5mm long. Easily recognizable by six prominent teeth on both edges of the prothorax and 3 ribs on the back; larvae are vermiform and resemble those of *Tribolium* but without the pointed ends.

BIOLOGY: This beetle is a secondary pest; larvae are very agile; they attack damaged and broken grain. Damage results more from the contamination caused by their activity than from the consumption of grain already damaged.

DEVELOPMENT: Optimum in 20 days at 30°C temperature and 80% - 90% relative humidity.

Limits: temperatures between 20°C and 38°C.
Relative humidity above 50%.

COMMODITIES CONCERNED: Cereals and by-products, dried vegetables.

8. SITOTROGA CEREALELLA

COMMON NAME: Angoumois grain moth, Alucite, Alucita.

ORDER: Lepidoptera

IDENTIFICATION: They are small light yellow moths (11 to 16mm); posterior wings end in a point and are fringed with very long bristles. Larvae are short, stout-bodied (6 to 8mm); young larvae enter the grain where they develop, feeding on the endosperm; when they move between grains, they weave a silk thread.

BIOLOGY: During the day adults remain inactive on the surface of stacks; they become very active in the twilight and can then infest growing cereal crops. Only larvae cause damage and their activity often gives an unpleasant flavour to the commodities they infest.

DEVELOPMENT: Optimum in 20 days at 35°C temperature and 75% RH
Limits: temperatures between 15°C and 35°C.

Relative humidity above 30%.

COMMODITIES: Mainly maize, but also other cereals such as rice, sorghum, wheat, barley, etc.

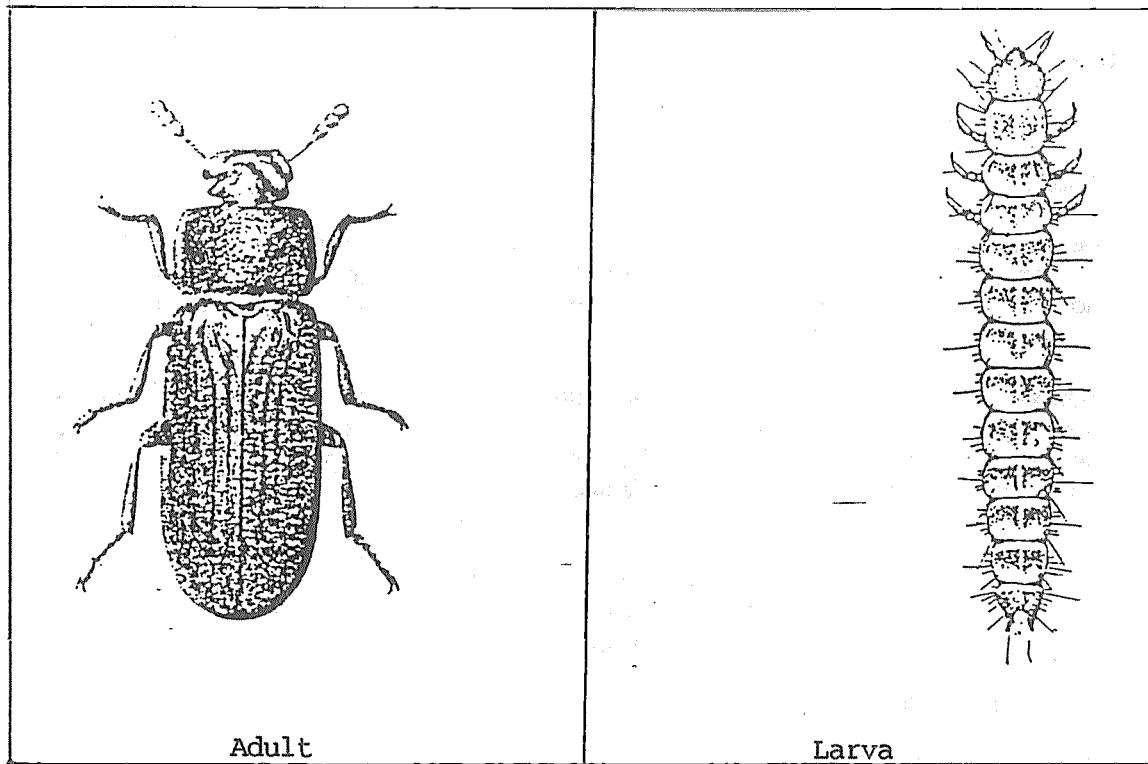


Figure 50: *Tribolium castaneum*

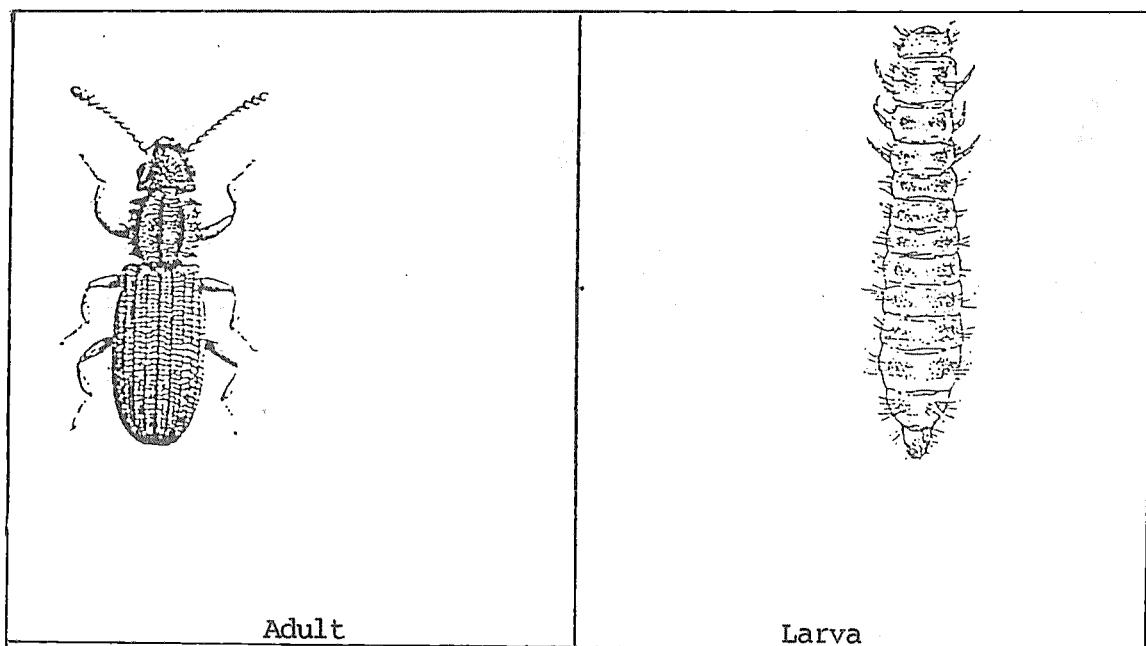


Figure 51: *Oryzaephilus surinamensis* (Saw-toothed grain beetle)

9. EPHESTIA

COMMON NAME: Moth

ORDER: Lepidoptera

SPECIES: *Ephestia elutella*
Ephestia kuheniella
Ephestia cautella

IDENTIFICATION: *Ephestia cautella* (a moth usually found in warehouses and cocoa) is 18 to 22mm in size, dull-coloured from grey to fawn with black spots; larvae are greyish.

BIOLOGY: Adults avoid light and only become active at twilight or dawn. Larvae move freely between grains they feed on. They downgrade commodities with their secretions and the greyish webs they weave.

DEVELOPMENT: Optimum at 30°C temperature and 70.80% RH.
Limits: temperatures between 15°C and 35°C.

COMMODITIES CONCERNED: Cereals and by-products, cocoa, peanuts.

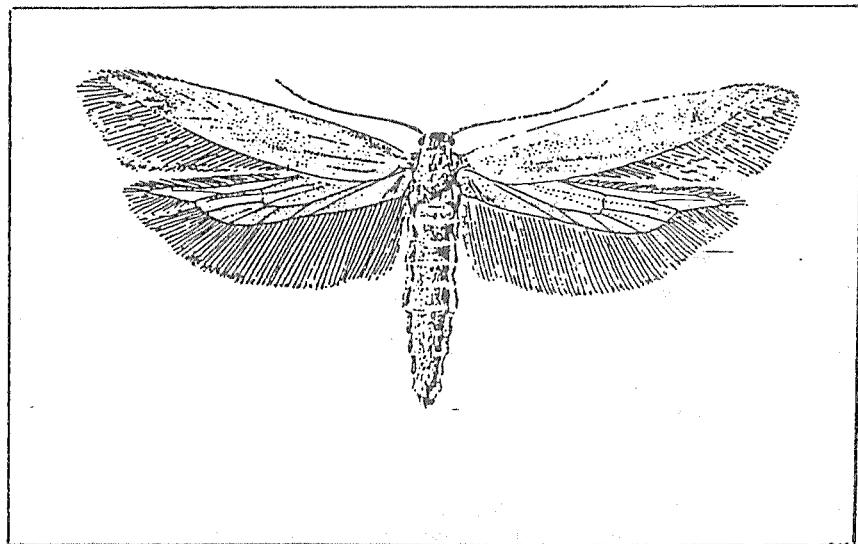


Figure 52: *Sitotroga cerealella* (Angoumois grain moth)

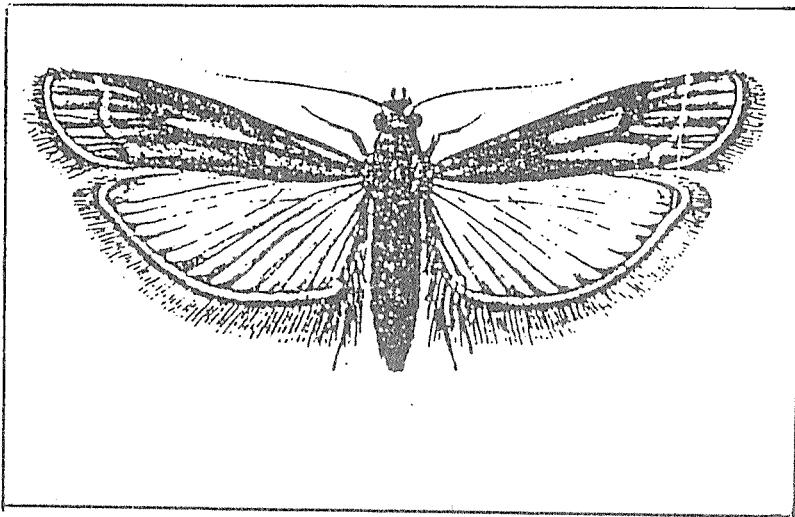


Figure 53: *Ephestia cautella* (Tropical warehouse moth)

ANNEX IV

HOW TO CALCULATE THE DIMENSIONS OF A WAREHOUSE FOR BAG-STORAGE

EXAMPLE

Determine, for instance, suitable dimensions for a store with an expected capacity of 1,000 tonnes of maize in jute bags; assume that the stored produce will be divided into 6 separate batches to facilitate good management, easy inspection and treatment.

A. FLOOR AREA REQUIRED FOR THE PRODUCE ONLY

It is found, from Table 4/1 giving the specific volume of bag-stored produce, that the required volume for 1,000 tonnes of maize is:

$$1,000 \text{ (t)} \times 1.8 \text{ (m}^3/\text{t)} = 1,800 \text{ m}^3$$

Assuming that jute bags will be stacked 4.5m high, the floor area required for storing 1,000 tonnes of maize is:

$$\frac{1,800 \text{ m}^3}{4.5\text{m}} = 400 \text{ m}^2$$

B. DIMENSIONS OF THE WAREHOUSE

For a warehouse, the length (L) generally equals twice the width (W) i.e: $L = 2 W$.

Therefore the area is:

$$S = L \times W = 2 W \times W = 2 W^2$$

As the floor area derived from calculation is 400 m²

$$2 W^2 = 400 \text{ m}^2 \quad \text{then } W = 14.14\text{m say } 14\text{m and}$$

$$L = \frac{400}{14} = 28.57\text{m say } 29\text{m}$$

C. STORED PRODUCE DIVIDED INTO SEPARATE BATCHES

The floor area required for the produce is shown in Figure 55/1; in Figure 55/2 the area is divided into 6 batches.

Batches are then arranged so as to provide for, e.g:

- a 3m wide central gangway for handling;
- two 3m wide transvers gangways;
- a 1m wide space along the walls for inspection purposes.

Separate batches are shown in Figure 55/3.

Therefore, the dimensions of the warehouse are:

$$\text{Width: } 1\text{m} + 7\text{m} + 3\text{m} + 7\text{m} + 1\text{m} = 19\text{m}$$

$$\text{Length: } 1\text{m} + 7.25\text{m} + 3\text{m} + 14.5\text{m} + 3\text{m} + 7.25\text{m} + 1\text{m} = 37\text{m}$$

The floor area of the warehouse is then:

$$19\text{m} \times 37\text{m} = 703 \text{ m}^2$$

A 1m wide space between the top of stacks and the top of walls should also be provided for inspection.

Therefore the height of walls is:

$$4.5\text{m} + 1\text{m} = 5.5\text{m}$$

The total store volume is then:

$$703 \text{ m}^2 \times 5.5\text{m} = 3866.5 \text{ m}^3$$

D. USE OF THE AVAILABLE STORING SPACE

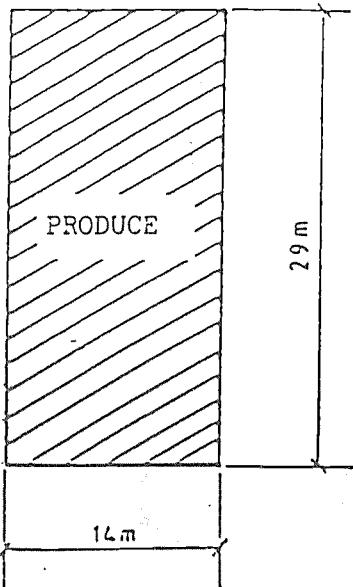
As the volume effectively used for the produce is $1,800 \text{ m}^3$, it can be said that the percentage utilization is:

$$\frac{1,800}{3,866.5} = 46.5\%$$

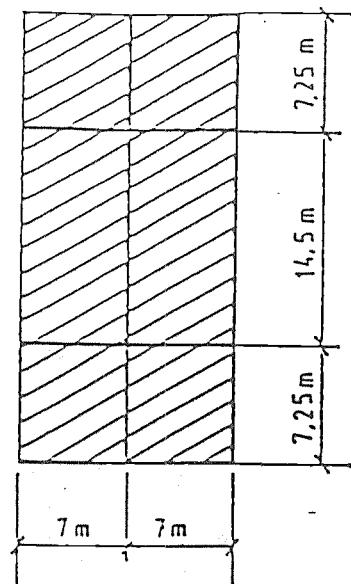
To increase, if necessary, the utilisation of the total volume, the number of batches should be reduced.

This theoretical calculation allows the dimensions for a warehouse to be rapidly determined. Nevertheless, the final dimensions may also depend on the standard dimensions used locally.

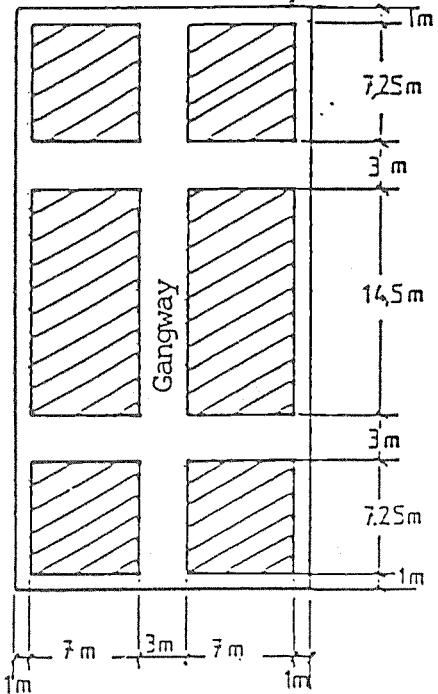
A covered space and annex facilities are also provided for, as shown in Figure 55/4.



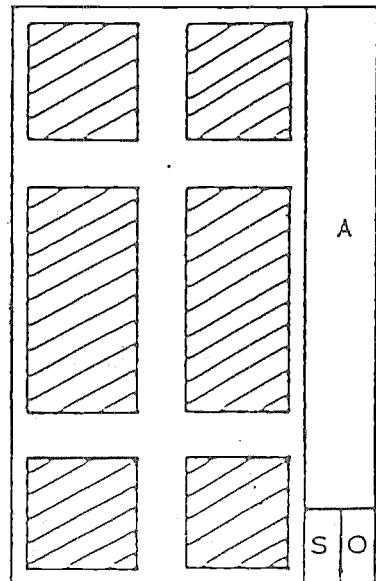
① Area required for the produce



② Area divided into 6 batches



③ Required area for 6 separate batches



④ Final diagram including
- working area : A
- annex facilities :
S: shed O: office

Figure 54: Calculation of the dimensions of a warehouse

ANNEX V

UNITS CONVERSION TABLE

LENGTH

1 metre (m)	= 39.37 inches (in)
1 metre	= 3.28 feet (ft)
1 metre	= 1.094 yards (yd)
1 kilometre (km)	= 0.62 miles

AREA

1 square centimetre (cm ²)	= 0.155 square inches (in ²)
1 square metre (m ²)	= 10.76 square feet (ft ²)
1 square metre	= 1.196 square yard (yd ²)
1 square metre	= 0.000247 acres
1 hectare (ha)	= 2.47 acres

VOLUME

1 cubic centimetre (cm ³)	= 0.061 cubic inches (in ³)
1 cubic metre (m ³)	= 35.315 cubic feet (ft ³)
1 cubic metre	= 1.308 cubic yards (yd ³)

CAPACITY

1 litre (l)	= 0.22 imp. gallon = 0.264 U.S. gallon
1 hectolitre	= 100 l = 0.61 imp. barrel = 0.84 U.S. barrel
1 litre	= 1.760 pints
1 m ³	= 1000 l = 227 U.S. gallon (dry)
1 imp. barrel	= 164 litres

MASS

1 gram (g)	= 0.0353 ounces (oz)
1 kilogram (kg)	= 1000g = 2.20462 pounds
1 ton	= 1000 kg = 0.9842 long ton = 1.10231 short ton

PRESSURE

1 pascal (PA)	= 1 N/m ² = 0.000145 pound force/in ²
1 atmosphere	= 760 mm Hg = 14.7 pound force/in ² (lbf/in ²)

ENERGY

1 Joule (J)	= 0.000947 B.t.u.
1 Joule	= 0.7375 foot pound-force (ft.lbf)
1 kilocalorie (Kcal)	= 4185.5 J = 3.97 B.t.u.
1 kilowatte-hour (kWh)	= 3600000 J = 3412 B.t.u.

POWER

1 watt (W) = 1 Joule/sec = 0.7376 foot pound/sec (ft lbf/s)
1 horsepower (hp) = 745.7 watt = 550 ft lbf/s
1 horsepower (hp) = 1.014 cheval-vapeur (ch)
1 kilowatt (kW) = 860 Kcal/h = 1.34 horsepower

TEMPERATURE

$^{\circ}\text{C}$ (Celecius or centigrade degree)
 $^{\circ}\text{F}$ (Fahrenheit degree)
 $^{\circ}\text{K}$ (Kelvin degree)

$$^{\circ}\text{C} = \frac{5}{9} (^{\circ}\text{F} - 32) \quad ^{\circ}\text{F} = 1.8 ^{\circ}\text{C} + 32 \quad ^{\circ}\text{K} = ^{\circ}\text{C} + 273.15$$

BIBLIOGRAPHY

- CENTRE D'ETUDES ET D'EXPERIMENTATION DU MACHINISME AGRICOLE TROPICAL.
1977 Manuel de Motorisation des Cultures Tropicales-Collection Techniques Rurales en Afrique. Paris: Ministère de la Coopération.
- CRUZ. J.F. Rapport de Mission FAO au Nicaragua - Conservacion de granos basicos. CEEMAT, Antony.
- CRUZ. J.F., TROUDE. F. Manuel de Conservation des Produits Agricoles Tropicaux. Paris: Ministère de la Coopération, à paraître.
- DEUSE. J. Protection Chimique des Denrées Stockées in Amélioration des systèmes post-récolte en Afrique de l'Ouest. Paris: A.C.C.T.
- DUCOM. P. Eléments d'écologie des stocks et de lutte contre les ravageurs in Amélioration des systèmes post-récolte en Afrique de l'Ouest. Paris: A.C.C.T.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
1983 Food Storage Manual. Rome: 2nd edition - World Food Programme.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
1984 Pertes de qualité des graines alimentaires après la récolte. Etude de la FAO. Rome: Alimentation et Nutrition no.29. FAO.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
1985 Plans standard pour magasins à grains en climats chauds et secs. Rome: Bulletin des Services Agricoles de la FAO. no.62.
- FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
1985 Manual of pest control for food security reserve grain stocks. Rome: Plant Production and Protection Paper No.63.
- GESELLSCHAFT FÜR TECHNISCHE ZUSAMMENARBEIT. Post Harvest Problems.
1980 Eschborn R.F.A: GTZ.
- GESELLSCHAFT FÜR TECHNISCHE ZUSAMMENARBEIT. Paddy deterioration in the humid tropics. Eschborn: GTZ.
- HALL. D.W. Manutention et emmagasinage des graines alimentaires dans les régions tropicales et subtropicales. Rome: FAO.
- MONRO. H.A.U. La fumigation en tant que traitement insecticide. Rome: FAO.
- MULTON. J.L. Conservation et stockage des grains et graines et produits dérivés. Paris: Editions LAVOISIER.

SCOTTI. G. Les insectes et les acariens des céréales stockées.
1978 Paris: Editions AFNOR I.T.C.F.

TROUDE. F. Méthodes, techniques, matériels pour éviter les pertes au
1980 niveau des stockages à moyenne et grande échelle. In
"l'amélioration des systèmes post-récolte en Afrique de
l'Ouest". Paris: A.C.C.T.

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