

Agrodok 31

**The storage of tropical
agricultural products**

Jelle Hayma

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Foreword

This Agrodok deals with the problem of storage of agricultural produce in the tropics and sub-tropics. Various methods of storage are discussed, together with the conditions needed and the problems arising during an extended storage period, for several groups of agricultural products.

The information is meant for those who are involved with providing information on storage to local people, and possibly small co-operatives.

The biggest silo mentioned in chapter 4 can contain 4.5 tons. If larger amounts have to be stored, the basic principles for storage remain the same. It might be wise however, to purchase an instrument to measure moisture content.

The purpose of this booklet is to provide information to make it possible to choose the most suitable storage method for local conditions. In order to keep the booklet simple, detailed building designs have not been included, but these can be obtained from Agromisa. The building designs are simple, and you certainly do not have to be a building expert to be able to use these. In general it is recommended that you adapt an improved storage technique to the local methods of storage, which will increase the chances of its success.

We would appreciate learning about your experiences with the storage of agricultural products, as well as receiving comments and remarks on this booklet.

Jelle Hayma

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1 Introduction

It is estimated that in the tropics each year between 25 and 40% of stored agricultural products is lost because of inadequate farm- and village-level storage. In the field and during storage the products are threatened by insects, rodents, birds and other pests. Moreover, the product may be spoiled by infection from fungi, yeasts or bacteria. In addition, for sowing seed it is important that the viability (its capacity to germinate) is maintained.

In order to minimize the losses during storage it is important to know the optimum environmental conditions for storage of the product, as well as the conditions under which its attackers flourish. These are dealt with in chapters 2 and 3. Chapter 4 discusses the importance of drying the product prior to storing it, and methods of doing this. Chapter 5 deals with the requirements and conditions for safe storage and describes various storage methods which are more or less suitable for the small farmer.

Farmers themselves have often developed methods for storing their products. Some of these traditional methods protect the product reasonably well and need at most slight improvements. On the other hand, it is possible that some traditional methods are unsatisfactory, and lead to high losses. Alternatively, the introduction of a new variety may alter the storage or drying requirements. A change in the market situation may also increase the need for other storage methods.

In the text "grains" are used to mean all kinds of products in grain form, so in general all seeds: cereals, beans, oil-containing seeds etc.

Much of the theory of the storage of agricultural products depends on the relative humidity of the air, and the moisture content of the products. Unfortunately, these properties cannot be measured in a simple and cheap way. For the sake of completeness, Appendix 1 gives a brief description of the main methods of measuring these properties.

2 Environmental influences on the stored product

2.1 Storage losses

Losses during storage may occur in many ways:

- losses in weight due to insects, rodents or birds eating the grain
- deterioration through fungus growth and rotting
- loss in quality through biting damage, insect and rodent excrement and fungus growth
- loss of motivation in the farmer to grow more, because he is not able to store his harvest or part thereof in a safe way for any long period of time
- damage to sacks, which causes waste during transportation
- decline in germination capacity of stored seeds (see chapter 3.2)

Insects

These are six-legged invertebrates. Their soft inside parts are protected by an external skeleton. The life cycle of an insect goes through the following stages: adult - egg - larva - pupa - adult. Adults and larvae damage grains, either by eating them or by spoiling them. Infected products also become more vulnerable to other insects, fungi and bacteria. Already in the field products may be infected by insects and during storage their number will rapidly increase. The female adults lay their eggs on the surface of a grain, between grains or sometimes inside the grain. The larvae hatching from the eggs are often the big grain eaters. A larva growing inside a grain eats out the inside of it. The pupa is the transitional stage between the larva and adult stages. During this stage the growing insect needs no food. From the pupa the adult emerges, and continues eating the grain and then lays more eggs.

Most of the insects that affect stored grains develop most rapidly at temperatures between 25 and 30 °C and a relative humidity in between 70 and 80%. However, they may still develop, although at a

lower rate, at lower or higher temperatures and relative humidity. (See figure figure 1 and chapter 2.2.)

Fungi

These are very small plants. They are not visible to the human eye, but fungi, or their spores ("seeds") are almost always present. In a warm and moist environment the spores will germinate and produce threads called hyphae. The hyphae penetrate the grain and convert part of it into other substances needed for their growth. A mass of hyphae, called a mycelium, can usually be seen with the naked eye or with a simple magnifying glass.

Fungi can damage the product in a number of ways:

- they can produce chemicals called enzymes which may stop seeds from germinating.
- they decrease the quality of the products for food, through discoloration or change in taste (bad flavour or smell), and they decrease the nutritive value.
- some fungi produce substances which are poisonous to people and animals.

Bacteria

These also cannot be seen by the naked eye, but occur almost everywhere, especially in moist environments. Under moist conditions they cause further deterioration of already affected grains and cause chemical changes and sometimes produce toxic substances.

Figure 1 shows the limits of temperature and relative humidity between which fungi, bacteria and insects may develop and when seeds will germinate.

Rodents

Rats and mice may cause considerable damage to crops in the field and products in storage. This can occur in various ways:

- consumption of part of the product
- contamination of part of the product with their excrement
- damage to buildings, storage containers and packing material

➤ they are also carriers of diseases which are harmful to people

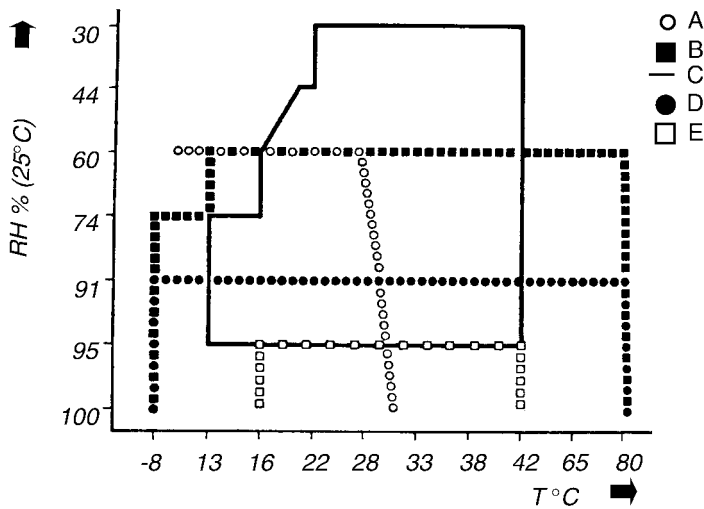


Figure 1: General limits of temperature and relative humidity for the multiplication of insects, fungi and bacteria and for the germination of seeds.

2.2 Moisture content and relative humidity

Biological activity occurs only when moisture is present. Therefore the moisture content of the product itself, as well as the moisture content of the surrounding air, is important for safe storage. Each product has its own characteristic balance (or equilibrium) between the moisture it contains and the water vapour in the air surrounding it.

This equilibrium is known as the moisture content/relative humidity pattern. Figure 2 shows some of these equilibria.

The moisture content of a product is expressed as a percentage of the wet weight:

$$\text{Moisture content (\%)} = \frac{\text{weight of water in the moist product}}{\text{weight of the moist product}} \times 100$$

The relative humidity is a percentage measurement of the amount of moisture (water vapour) actually in the air as compared to the maximum amount of moisture which air could hold at that temperature. In formula, for a certain temperature:

$$\text{Relative humidity (\%)} = \frac{\text{amount of water vapour present in the air}}{\text{maximum amount of water vapour that air of that temperature can contain}} \times 100$$

Warm air can contain more moisture. Therefore, if the amount of moisture in the air is constant and the temperature increases, the relative humidity will decrease.

From figure 2 it can be seen that for example cocoa beans, when in equilibrium with air that has with a relative humidity of 70%, have a moisture content of 8%. If the relative humidity of the air decreases to say 40%, the cocoa beans will lose moisture until a new equilibrium is reached: the moisture content of the beans will decrease to 6%.

The maximum allowable moisture content for safe storage of a product, known as the safe moisture content is taken to be the equilibrium moisture content which corresponds to a relative humidity of 65 - 70%. When a product's moisture content is equal to or below the safe moisture content, the danger of attack by bacteria and fungi is negligible.

Table 1: Safe moisture contents for various groups of products.

| Product | Safe moisture content |
|------------------|------------------------------|
| Cereals | 12-14% |
| Beans, pulses | 13-15% |
| Oil crops | 6- 8% |
| Roots and tubers | not applicable |

If a product has to be stored for sowing seed, a lower moisture content should be maintained (see chapter 3.2).

Cereals dried to 12 - 14% moisture are free from fungal growth, but still can be very attractive to insects. In order to slow down insect development the moisture content should be 9% or less (see figures 1 and 2).

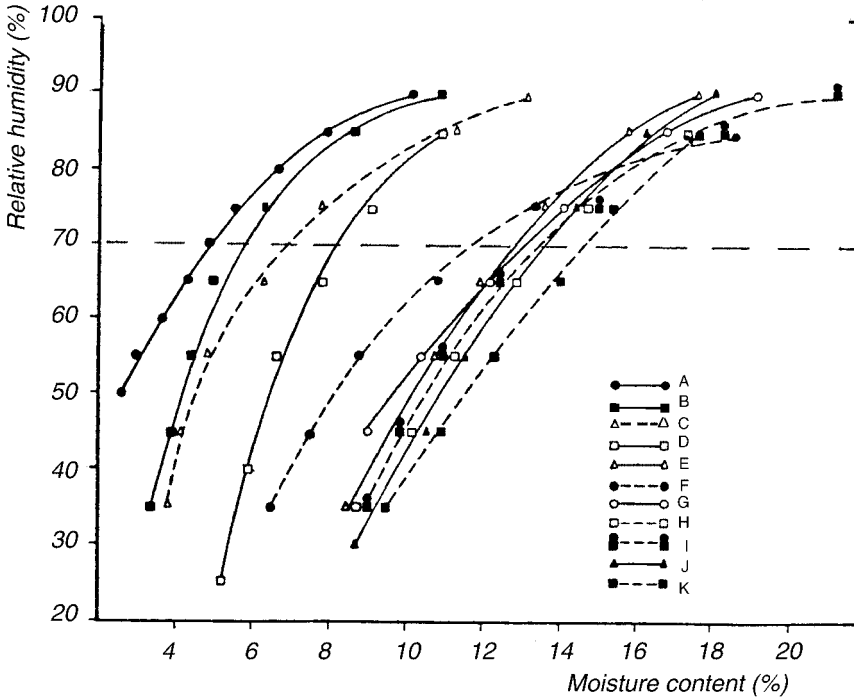


Figure 2: Moisture content/relative humidity equilibrium curves. A: Copra, B: Palm kernels, C: Shelled groundnuts, D: Cocoa beans, E: Paddy, F: Soybeans, G: Maize, yellow, H: Maize, white, I: Coffee beans, J: Sorghum, K: Rice, polished.

For root crops a general safe moisture level cannot be recommended: for certain storage methods of roots and tubers the relative humidity should never be below 80% (see also chapter 3.4). Unfortunately moisture content of these cannot be measured in a simple and cheap way. Fortunately there are some traditional methods (feeling, biting etc.) which yield, with some experience, reasonably reliable estimates of the moisture content.

In appendix 1 the main methods for measuring the moisture content of the product, and the relative humidity of the air, are described.

2.3 Temperature and respiration

The stored products, as well as the organisms attacking stored products are living things: they breathe. During respiration ("breathing"), oxygen is used up and carbon dioxide, water and heat are produced. The rate of respiration, and thus the amount of carbon dioxide, water and heat that are produced is strongly dependent on the temperature and the moisture content of the product. The rate of respiration is reduced approximately by one half for each 10°C reduction in temperature.

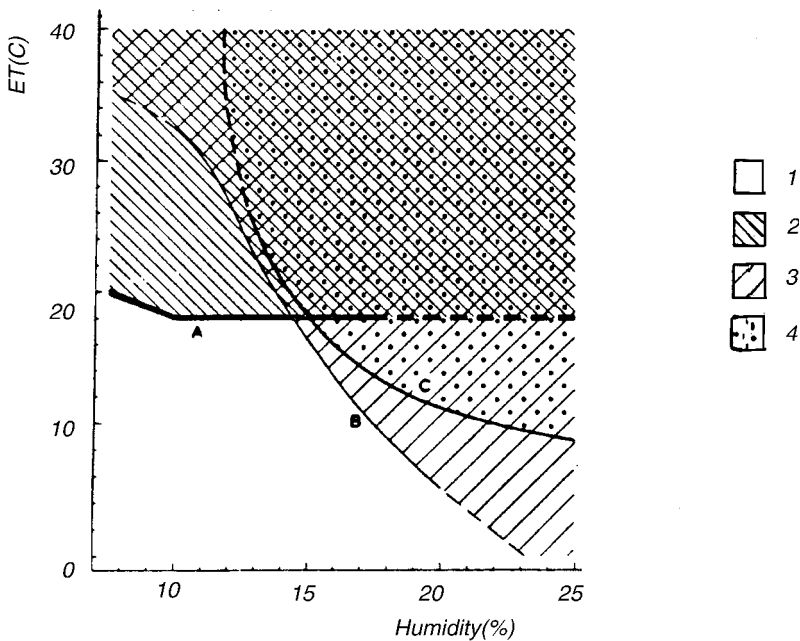


Figure 3: Values of temperatures and moisture content for safe storage, insects and fungal heating and fail in germination.

A: lower limit for insect heating

B: lower limit for germination

C: lower limit for fungal heating

1: Safe, 2: Insect heating, 3: Fall in germination, 4: Fungal heating.

Figure 3 correlates temperature and moisture content values for cereals and indicates their influence on insect and fungus development and on the decline in germination capacity. In general, the higher the temperature the lower the moisture level must be in order to reduce deterioration. The lower the temperature, the higher the permissible moisture level for safe storage.

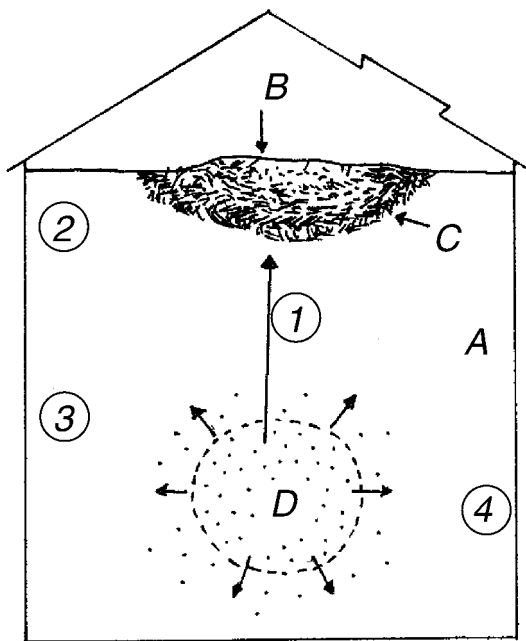


Figure 4: The consequences of a 'hot spot' caused by insects: spreading of the insects and condensation of water vapour with consequently fungal growth and sprouting.

A: Grain, B: Sprouting, C: Mouldy.

1: Condensation near cool surface from warm moist air produced by insects, 2: Damage due to moisture rising from "hot spot", 3: "Hot spot" spreading, 4: Insects spreading as heat increases, 5: "Hot spot" caused by insects.

In fact, respiration is a self-accelerating process. The moisture produced during respiration can increase the moisture content of the product which in turn will create favourable conditions for fungus growth. Normally the respiration rate of well-dried products with a low moisture content, such as cereals, beans and sowing seed is extremely low and therefore no rise in temperature will occur spontaneously. Consequently the storage temperature is not of such great importance, provided the products are stored as cool as possible. This can be achieved in the following ways:

- Leave artificially dried products to cool first before storing them
- The storage room should have a large overhanging roof of such a size that the walls are always in the shade.

Temperature variation inside stored products should be avoided. Locally higher temperatures may occur in the centre of grain stored in bulk in a silo, or be caused by big differences in day and nighttime temperatures, especially in metal silos. These so-called "hot spots" can also be caused by insects. The consequences of a "hot spot" are shown in figure 4. If the product is uniformly dry when put into storage, and is kept dry and at a constant temperature, damage due to condensation and transference of moisture will be minimal. Products with a high moisture content (root crops) have a fairly high respiration rate (see also chapter 3.4). Therefore high temperatures during storage limit the storage period. Every degree that the temperature can be lowered means a longer storage period.

3 Storage of various groups of agricultural products

3.1 Cereals and pulses

Conditions for storage

When dried to moisture contents below the safe moisture level, cereals and pulses can be stored for periods of a year or more under a wide range of temperatures, provided that during storage the moisture level does not rise, and precautions against insects are taken; insects may still develop at a relative humidity of approximately 35% and temperatures of around 15°C.

Table 2: The safe moisture content for any particular grain may vary slightly depending on the variety (valid for temperatures up to about 27 °C).

| | product | safe moisture content (%) |
|-------------|--------------------------|---|
| cereals: | maize, threshed, yellow | 13.0 |
| | maize, threshed, white | 13.5 |
| | maize flour | 11.5 |
| | paddy | 14.0 |
| | husked rice (brown rice) | 12.0 |
| | sorghum | 13.5 |
| | millet | 15.0 |
| | wheat | 13.5 |
| | wheat flour | 12.0 |
| | pulses: | white and kidney bean, broad bean, cowpea |
| lentil, pea | | 14.0 |

The safe moisture content for any particular grain may vary slightly depending on the variety. The mentioned safe moisture contents are valid for temperatures up to about 27 °C. Higher temperatures require lower moisture content maxima.

Drying (see also chapter 4)

Often the products are dried in the field as much as possible. After cutting, cereals are tied into sheaves that are laid or hung on different kinds of racks or piled into stacks. After harvesting, pulses are often left lying on the ground to let the leaves die off. The pulses are then dried with the foliage still attached on well-ventilated racks or platforms. During this pre-storage drying period, and sometimes even before harvesting, the products may easily become infested with insects. When the products have reached the safe moisture content, they can be stored permanently. Often they will be threshed first, as the threshed product takes up less storage space.

Even if the product is still too moist, it can be stored, if, during storage, it can dry further. This will require very good ventilation. This can be better achieved by storing the grain not threshed. Maize can be stored in maize cribs; millet, sorghum, rice and pulses in baskets. The advantage is that threshing can be postponed until more time is available. A disadvantage is that more storage space is needed and that cribs and baskets protect the grain only poorly against insect attacks. If necessary, they may be threshed when the safe moisture level has been reached and they can then be stored in a less voluminous and better protected way.

Threshed cereals and pulses can be further dried, if necessary, in the sun on a threshing floor, mats or canvas, or artificially.

Storage methods

(see also chapter 5)

The following two factors determine the choice for the best storage method:

- the moisture content of the product when it comes from the field
- the relative humidity of the outside air during the storage period

Depending on the weather during the harvesting period and the duration of storage there are four possible combinations:

Dry harvesting period and dry storage period.

There are no problems with storage, provided that the general conditions are fulfilled. All methods (1 - 11) mentioned in chapter 4 are suitable.

Dry harvesting and wet storage period.

The dried product will take up moisture from the more humid air during storage, unless it is stored in airtight and waterproof conditions. This makes storage more expensive. Depending on the necessary time, use and available materials, the threshed product can be stored in the following ways:

in small quantities:

- in airtight gourds (method 1)
- in plastic bags (method 5)
- in well closing metal drums (method 8))

for daily use:

- in an improved mud-block silo (method 6, figure 23), made air- and watertight
- in a Pusa bin (method 7); a silo made of clay, plastic foil and metal strips with an outflow opening

for occasional use:

- in airtight and waterproof silos (methods 7-10)

for very long storage:

- in an underground pit (method 11), that is made air- and water-tight

Wet harvesting and dry storage period.

During storage the still moist product has to dry and therefore it should be ventilated as much as possible and thus loosely packed:

- in a thin layer
- not threshed in a ventilated structure in baskets (method 2)
- in a maize crib (method 3)
- in jute sacks (method 4)

- in sealed silos (method 6 - 11), provided it is dried and threshed first

Wet harvesting and wet storage period.

The product should be dried artificially and then, after threshing, be stored in an airtight and waterproof container.

Remarks

If undamaged, husks or pods offer some protection against insect attack (maize, paddy, beans). If the rice husks are not damaged during harvesting and drying (for example cracking may occur) it can best be stored as paddy. Traditional maize varieties often have husks that cover the whole cob. If still intact this provides good protection against insects. Unfortunately this is not always the case with improved varieties. For prolonged storage it is important to select cobs with undamaged husks that cover the whole cob. Kernels inside the unhusked cob should not have a too high moisture content when coming from the field (not more than 26%) because the unhusked cobs will soon go mouldy: the husk provides favourable conditions for fungus growth. Prolonged storage of beans in very dry conditions will result in excessive hardness which will make cooking more difficult. Nevertheless this risk may be preferable to the risk of mould damage.

3.2 Sowing-seed

Conditions for storage

The main aim when storing sowing-seed is the preservation of the seed viability. For that purpose the seed has to be stored within certain limits of temperature and humidity. These limits vary for seeds of different species and varieties.

In general the following can be stated:

- For seeds with a moisture content between 5 and 14% every 1% decrease in moisture content doubles the possible storage time. Below 5% oxidation processes may play a role. Above 14% fungal growth causes rapid degeneration.

- Every 5 °C decrease of the storage temperature doubles the possible storage time. For prolonged preservation of the seed viability the time of harvesting is very important. Seed that is harvested when still unripe loses its viability sooner than well-ripened seed.

Before sowing the seed, its capacity to germinate should be tested with, for example, 100 seeds.

Damage to sowing-seed

Damage to sowing-seed can be caused by the following factors:

Mechanical damage to the seeds.

This depends on the method of harvesting and threshing. Fast rotating harvesting and threshing machines, flails and the use of animals for threshing increase the chance of broken grains. The moisture content of the seed also plays a role: dry seeds with a moisture content of for example 8% are more sensitive to breaking than seeds with a moisture content of 14%. If many broken grains are present, the chance of infection by insects and fungi is greater, which results in a further decrease in the germination capacity.

The occurrence of fungi.

This is related to the temperature and the moistness of the stored seed and its environment. At a moisture content above 7 - 9%, fungal growth may occur; at a moisture content above 18 - 20%, heating by fungi may take place. Above 40 - 60% germination may occur. Most seeds retain their viability when their moisture contents remain below 7 - 9%. Coffee, cocoa, oil-palm and citrus seeds are exceptions, since they have to be stored under humid conditions. If the temperature is too high the viability of the seeds also decreases. For example: artificial drying with hot air at 50 °C for a couple of hours at an original moisture content of 20%, strongly reduces the viability of several types of seeds (see also the following section on drying of sowing seed).

Insect damage.

This can occur in the following ways:

- damage to the germ (embryo) of the seed
- eating other parts of the seed, which also reduces the viability
- polluting the seeds, which then require cleaning, leading to seed loss
- increasing the temperature and humidity so that condensation may occur, which enhances the possibility of fungal growth (see also figure 4).

Drying of sowing seed

Too high drying temperatures cause the kernels of some grains to break and may kill the seed embryo. Therefore drying of most sowing seeds is best done at a maximum temperature of 35 °C. Only cereals can withstand temperatures of 40 - 45 °C. That is why sowing seed is not dried in full sunlight, but in the shade. Very moist seed can stand less high temperatures during drying than drier seed. The effectiveness of drying depends on the humidity of the air and the wind velocity in the area concerned. Air-dried seeds that are dried in the rainy season still contain about 13% moisture, while the safe limits for sowing seed are as follows:

- | | |
|---------------------------------------|-----|
| ➤ cereals (rice, maize, sorghum etc.) | 10% |
| ➤ pulses | 8% |
| ➤ vegetable seed | 6% |

Therefore artificial drying is recommended in areas where the humidity of the air is high. This can be done in the following ways:

- with the help of artificial heating by a lamp, a running engine or an oven (not too hot).
- with water-absorbing materials such as silica gel, quicklime (un-slaked lime), wood or straw ash, clay (dried in an oven), etc. The air dried seeds are mixed with one of these materials and then packed in airtight containers (see the section on airtight storage under storage methods for sowing seed).

Seeds can also be kept dry with toasted rice: the rice is toasted in a shallow pan until it is light brown in colour. The toasted rice acts as a desiccant: it absorbs water from the product with which it is stored.

Seed disinfectants

Fungicides.

These are chemicals that kill fungi. Those such as mercury compounds and dithiocarbamates do not harm the seeds at all.

Insecticides.

Chemicals that kill insects are in general more harmful; especially **lindane** may affect the seed viability. If one wants to store disinfected seeds, the moisture content of the seeds must be at the safe level before disinfection, because disinfectants in powder form absorb moisture.

Fumigants.

These are chemicals which are active in their gas form for killing insects. These are harmful to seed viability, especially when the moisture content of the seed is high. Particularly **methylbromide** and **ethylenedibromide** are known for this. **Phostoxin** is harmless for sowing seed and also is easier to use in its tablet form. **Because of the toxicity of fumigants (very poisonous to man and animals), it is advisable that only experts use them.** If you still want to use them, it is advisable to gas a small amount of seed as a trial, in order to test the seed viability after the treatment. Seeds with a high oil content require quick aeration after gassing.

Disinfected sowing seed should be kept apart from seed for consumption!

Storage methods for sowing seed

In general seed should be stored well dried and as cool as possible. The better the first condition is fulfilled, the less important the second becomes.

Cool storage

At a temperature below 10 °C it is possible to store seeds with a moisture content (slightly) above the already mentioned safe limit (see also figures 2 and 3). A refrigerator is required for this, so the method is only suitable for small quantities, for example vegetable seeds.

Airtight storage (ambient temperatures).

The seeds have to be dried very well and, if possible, mixed with a moisture absorbing material and/or appropriate seed-protecting chemicals. The sowing seed then is best stored in one of the following containers:

- polythene bags, thicker than 0.25 mm, that are sealed by melting (for example with an iron and a newspaper).
- earthenware pots or gourds, that are made airtight with paint, varnish or linseed oil, then covered with wax.
- glass jam-jars with good screw-tops.
- tins that are closed airtight or can be made airtight with candle wax for example.
- paper bags with an intermediate layer of aluminium foil.
- oil drums with screw-tops.

For further information on storage of sowing seed see also chapter 5 and storage methods 1, 5, 7 and 8.

3.3 Oil-containing products: groundnut, soybean, sesame, cotton-seed, palm-kernel, copra

Oil-containing products are used for direct consumption (groundnuts, soybeans, sesame, coconut) or for the extraction of oil. Often the remaining material (the "press cake") can be used as cattle feed.

The value of the oil is determined for a large part by the free fatty acid content. This influences the smell and taste of the oil in a negative way. This is especially important if the oil is used locally. The process that liberates these free fatty acids (lipolysis) goes faster at a higher

temperature and humidity. The enzymes that play a role in this process are already present in these products naturally, but are produced in greater quantities when infection by insects and fungi and mechanical injury occurs. Apart from influencing taste and appearance of the dried products as well as the oil to be pressed from it, fungi can also form toxic substances like aflatoxin in groundnuts. Fungal growth on oil-containing products takes place at a moisture content above 7 - 8%.

Table 3: Safe moisture content of oil-containing products.

| product | safe moisture content |
|----------------------|------------------------------|
| groundnuts (shelled) | 7% |
| copra | 7% |
| palm kernels | 5% |
| cotton seed | 10% |
| soybeans | 13% |

Drying

Groundnuts, soybeans and sesame are first dried in the field with the foliage still attached. Afterwards they are threshed or picked by hand. A moisture content of 15% seems the most suitable for picking by hand and threshing with flails or simple stripping machines. The latter methods give a high percentage of broken groundnuts, which increase the chance of infection by fungi and insects. When threshing mechanically, it is possible to thresh at a higher moisture content, which results in less damage. The picked or threshed products can be dried further on mats or canvas (see figure 5).

If these products are stored in jute sacks, some additional drying will take place, provided the sacks are piled loosely. In the rainy season the additional drying should be done artificially.

Storage of too moist products increases the possibility of internal heating. Palm kernels are very difficult to store without loss of quality and have to be dried very well. For prolonged storage of coconuts the coconut meat should be dried from the original moisture content of about 50% to about 6%. The nuts are cut in half and are dried in the

sun or artificially or by a combination of both. For sun-drying 60 - 80 hours of sunshine are required; if it takes longer than 10 days the coconut will spoil. They are covered at night against dew formation and during rain, or the drying racks can be stored under a roof. The meat is removed from the shell after about 2 days and 3 - 5 days are then necessary to complete the drying. Artificial drying can be done with hot air. Temperatures above 77 °C should not be used, except in the initial stage; later, the temperature is reduced to 65 °C or less. Smoke affects the quality (see chapter 3). Before drying artificially it is advisable to dry the halved nuts in the sun for 1 or 2 days.

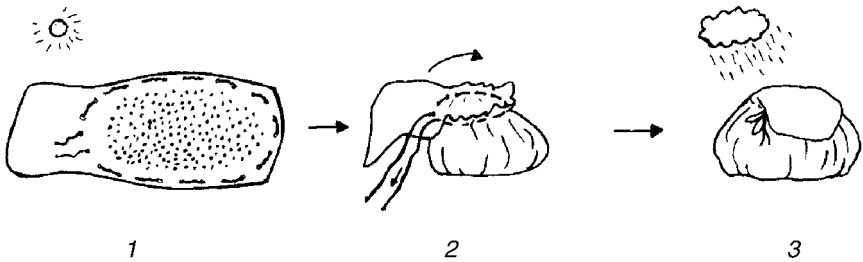


Figure 5: Plastic or canvas (1) that can be closed up by pulling the cord (2) and covered with a flap (3).

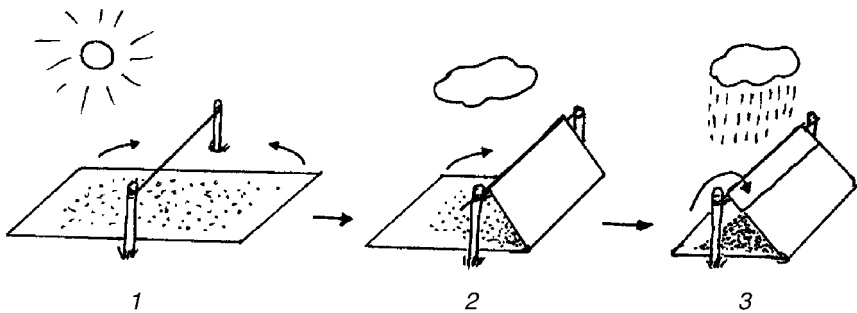


Figure 6: Plastic or canvas (1) that can be folded (2) over a rope in case of rain (3).

Estimation of the moisture content of the dried meat (copra):

- 0-7%: brittle, breaks easily, small slices burn with a clear steady flame
- 7-10%: the flame splutters
- > 10%: it will not burn

Storage methods (see also chapter 5)

Methods 1, 2 and 4 - 10 are suitable for storage of oil-containing products. When using the airtight methods, it is important to have a very well dried product at the beginning of the storage period. In the humid tropics methods that allow ventilation (methods 2 and 4) have to be used where airtight storage is not possible.

Groundnuts have to be stored in the shell as much as possible, as this gives protection against insects and fungi. After shelling, quality and viability deteriorate rapidly. If jute sacks are used (method 4) coarsely woven sacks prove to be better from the point of view of ventilation, but they increase the possibility of insect attack. Storage in big baskets is satisfactory.

3.4 Root crops: yam, cocoyam (taro, tannia), sweet potato, Irish potato, cassava

Conditions for storage

Root crops, crops producing root or stem tubers, have special requirements with respect to storage, because of the high moisture content of the tubers (60 - 80% when fresh). On the one hand desiccation should be avoided, on the other hand one has to guard against too much humidity around the tubers, which may cause rotting. Living tubers continue to breathe fairly intensively, and this increases at higher temperatures. When high tuber temperatures are combined with airtight storage, lack of oxygen occurs, which results for example in potatoes with black hearts. As the temperature of the product is higher better ventilation is necessary. During storage chemical changes take place in the tubers which may influence the firmness and the taste.

Tubers have a dormancy of a certain period. After this dormant period they start to sprout. This period varies with the crop and the variety and the temperature of storage of the tubers. Yams can be stored for

about 4 months at a normal temperature without sprouting but potatoes already start sprouting a little after 5 weeks at 15 °C. Also the tubers are often attacked by rodents during storage.

Without cooling the keeping quality of tubers decreases in the following order: Yam, cocoyam, sweet potato, cassava. Also for each root crop, varieties are known that keep well and others that do not.

Curing

In order to make the tubers more suitable for storage they can undergo a special treatment, called "curing". The tubers are stored under very warm (25 - 35 °C) and very humid (90 - 95% relative humidity) conditions for several days. During this time a layer of cork cells, a few cell layers thick, is formed around the tubers. This layer greatly reduces the desiccation process and largely prevents infection by bacteria and fungi. Although the curing process goes faster in full sunshine, it is better to protect the tubers against the sun with big leaves, because otherwise the relative humidity around the tubers decreases rapidly and the strong heating of the tubers initiates processes that reduce the keeping quality.

Harvesting

Rotting begins with wounds that are inflicted during harvesting and transport. Therefore harvesting should be done as carefully as possible, preferably with wooden tools. If the root crop is planted in rows and in ridges, the tubers can be lifted if they are not too far apart. The lifting tool should be able to pass easily underneath. More than 50% of big tubers are often damaged, but only about 5% of the small ones. Damaged ones should be consumed immediately or should be specially treated. Rubbing the damaged spots with sieved wood ashes, with lime or with chewed cola nuts and drying in the sun for 1 or 2 days heals the wounds and notably decreases the chance of rotting.

Storage methods (see also chapter 5)

The lower the temperature the lesser the likelihood of desiccation and rotting, of lack of oxygen and of sprouting. In other words: keeping low temperatures during storage is the best method. However, in prac-

tice this is usually not possible, since artificial cooling mostly is very expensive. Wheat can be done is to keep the storage room as cool as possible and well ventilated. If ventilation can be regulated, for example by using a ventilator or in a barn with adjustable ventilation valves, the place should be ventilated during the coolest time (the night) and insulated during the hottest time to trap the cool air. However, this requires a thick walled storage room. With natural ventilation, for example in huts, hardly anything can be regulated and thick walls are of little use. The cooler the conditions (which will depend on, among other things, season and altitude), the less ventilation is needed, but the chances of rotting and internal heating (see chapter 2) are higher.

Yam, sweet potatoes and cassava should not be cooled below 12 °C. They can be left in the ground during the dry season without harvesting. The quality remains reasonable, though often the tubers become more fibrous. Although this method seems very attractive, there are several disadvantages:

- the land is occupied longer, so other cultivation cannot take place during that period
- the tubers are not harvested at the optimum time
- the tubers cannot be protected against termites, rats, monkeys, thieves etc.

In chapter 5 the two most common methods of storage are dealt with: clamps (method 12) and huts (method 13).

Cassava

Curing:

Temperature 30 - 35 °C, relative humidity 80 - 95%, 4 - 7 days; wounds should be treated and left to dry.

Storage:

Freshly harvested tubers deteriorate rapidly: deterioration commences 1 - 7 days after harvesting.

Simple techniques such as reburial, keeping under water, smearing with mud or stacking and daily watering suffice to preserve the tubers for a few days. Mostly the tubers are "stored" by leaving them

in the ground and harvested when needed. Pre-harvest pruning considerably extends the storage life of the tubers: 1 - 4 weeks before harvest all foliage is removed by pruning, leaving approximately 20 cm of stalk in the ground. If a piece of the stalk is left attached to the tuber during harvesting, the chances of rotting are less.

Methods:

- In field clamps (method 12).

Storage in layers alternating with layers of sand have given good results in Colombia.

- In huts (method 13).

Freshly harvested tubers are packed with moist sawdust in wooden boxes. If sawdust is not available coir-dust or peat may be used instead. Rice-husks are unsuitable. The moisture content of the sawdust packing should be about 50%; this maintains a high relative humidity which promotes curing and prevents excessive moisture loss, but does not wet the roots which would lead to rotting. The tubers maintain a good quality after 1 - 2 months storage. Recent experiments indicate that cassava leaves may be a better preservation medium than moist sawdust: alternate layers of tubers and leaves (in a 3 - 5 cm thick layer) in a wooden box or bamboo basket or in a clamp. Again, better results will always be obtained if the tubers have little or no damage and are handled with care. A delay in packing after harvest will result in a lower recovery. The boxes should be placed in a well ventilated hut.

- Storage in the field.

Besides the already mentioned disadvantages the following should be noted. Short-season varieties, maturing as early as 6 months after planting, cannot be left in the ground for more than 9 - 11 months without serious deterioration. Long-season varieties, taking at least a year or more to mature, sometimes can be left in the ground for 3 - 4 years without serious deterioration. The first group is often sweet cassava, while the second group tends to be the bitter variety which is less attractive to animals such as wild pigs and baboons.

- Freshly harvested tubers may be processed into various dried products with a longer storage life. The tubers can be sliced and dried in the sun, with or without parboiling (which enhances the keeping quality), and may be stored for several months.

Yam.

Curing:

Temperature 29 - 32 °C, relative humidity 90 - 95%, 4 days.

Satisfactory healing only occurs around deep wounds such as knife cuts. Bruised tubers (with superficial wounds) do not respond to curing. Such tubers can only be preserved by cutting off the bruised parts before curing.

Storage:

The production of yam, unlike that of cassava, is very seasonal and therefore the tubers have to be stored for several months. The termination of dormancy (when sprouting starts) is the main constraint to long term storage. Removal of the shoots extends the storage life. Storage conditions for cured tubers: approximately 16 °C and 70% relative humidity. Above 16 °C the tubers can be stored for 3 to 4 months. Uncured tubers should be stored at a relatively low humidity. Below 12 °C chilling injury occurs.

Methods:

- During the dry season yams can be left unharvested in the ground without appreciable loss of quality, but are for several reasons normally harvested for storage.

➤ Yam "barn"

Basic design: vertical framework 2 m. or more high to which individual yam tubers are tied with a rope along cross members of lightweight timber. The yams may also be tied to the upright poles so that the axis of the tuber lies in the horizontal plane. A thatched roof of palm leaves may be constructed or the barn can be built under the dense shade of forest trees. These structures provide adequate ventilation and protection from termites, but not against theft. Also the tubers can be inspected daily and rotting

tubers cannot infect the other ones. As soon as the rainy season begins, the tubers in the yam barn begin to deteriorate rapidly.

➤ In huts (method 13)

After curing the tubers are stored in heaps on the floor, in boxes or on shelves or racks in such a way that air (wind) can pass everywhere. The higher the temperature and the relative humidity, the more ventilation is needed. Also the maize crib (method 3) can be used for storage, provided the roof is large enough to prevent irradiation by the sun.

➤ Small amounts of well dried tubers can be stored in earthen silos (method 6). It is also common to find yams stored in pits or piled into heaps, protected from sun and flood water.

Sweet potatoes

Curing:

Temperature approximately 30 °C, relative humidity 85 - 90%, 5 - 7 days.

The tubers can be left in the field in small heaps that are covered at night with straw or jute sacks if the temperature drops below 25 °C.

Storage:

The sweet potato has low storage potential in the tropics. Optimum storage conditions after curing: 13 - 16 °C and high relative humidity (85 - 90%). Higher temperatures promote sprouting and increase respiration, leading to heat production and dry matter loss. Ventilation during storage is of great importance. The tuber is highly susceptible to physical damage and subsequent deterioration. Red varieties seem to be stored better than white varieties. Storage loss can in fresh tubers can be lessened by processing: peeled tubers are sliced and sun dried to produce chips which can be stored intact or ground into flour.

Methods:

- Clamp storage (method 12).
- Pit storage (method 11).

The pits are lined with straw or bamboo and covered with a tight-fitting (wooden) cover and a roof for protection from the rain. Only possible in areas of good drainage.

➤ Hut storage (method 13).

The cured tubers can be stored by wrapping them in newspaper or packing them in dry sawdust. (The sawdust must be dry in order to minimize regrowth and rotting.) They can also be stored in crates lined with plastic. Holes in the plastic allow for ventilation. During the first week curing is allowed to proceed at ambient temperature (18 - 31 °C). After curing excess moisture must be removed to prevent sprouting.

Potatoes

Curing:

Temperature 8 - 20 °C, relative humidity approximately 90%, 5 - 8 days.

Condensation of water on tubers must be prevented.

Storage:

Optimum storage at temperatures below 10 °C. Potatoes are a sensitive product with respect to oxygen need, damaging and infection by fungi etc. Potatoes should not be exposed to the sun too long (maximum 1 hour). They should be stored in the dark in a dry and well ventilated place. Under certain tropical conditions potatoes may be left in the ground for a period beyond the time at which it would normally have been harvested under temperate conditions.

Methods:

➤ Storage in clamps or (partially) underground pits.

Because the rate of respiration is still very high in the beginning the final layer of sand is sometimes applied to the straw after one week.

➤ Hut storage (method 13).

The stores are ventilated during the night when the temperature is lower. The stores may be built partially underground with air

ducts under the tubers to utilize cool night air. Storage in bulk or preferably in small boxes.

4 Drying

4.1 Relative humidity of the drying air

In chapter 1 it was pointed out that in the course of time the moisture content of a product reaches an equilibrium with the moisture content (relative humidity) of the surrounding air. In general safe storage of a product is reached below or at the equilibrium moisture content that corresponds with a relative humidity of 70% or lower. For sowing seed the **upper limit** is 40%, for tubers the **lower limit** is 80%. A product loses water (ie. it dries out) when the relative humidity of the drying air is lower than the equilibrium relative humidity that corresponds with the moisture content of the product. The larger the difference between these two relative humidities, the faster the drying process goes.

Example: From figure 2 it can be seen that paddy with a moisture content of 16% is in equilibrium with the air which has a relative humidity of 84%. In order to dry the paddy the relative humidity of the air has to be below 84%. Moreover the relative humidity of the drying air has to be below 70% in order to dry the paddy to below the safe moisture content of 13% (see figure 2).

4.2 Temperature of the drying air

When air is heated it can contain more water vapour, resulting in a decrease in its relative humidity: with a temperature increase of 1 °C the relative humidity of the heated air will decrease by about 4%. Therefore a product dries better in hotter air. When air cools off, its relative humidity increases (which is what happens during the night) and the product will dry less and at a slower rate or may even become moister. Drying and ventilation can be done best by day, except for tubers. At night it is often better to cover the product in order to prevent dew formation and attraction of moisture coming up from the ground. If the product has to endure too high temperatures during drying (above 40 °C), the viability decreases, which is especially disadvantageous for sowing seed.

Table 4: The highest safe temperatures for drying.

| Use | Maximum temperature (°C) |
|-----------------------------------|--------------------------|
| livestock feed | 74 |
| human food, except rice and beans | 57 |
| grain for milling | 60 |
| brewery uses | 43 |
| sowing seed | 43 |
| rice for food | 43 |
| beans for food | 35 |

Drying at a temperature lower than the highest safe temperature usually gives a better quality dry grain. Also, as a rough rule, lower temperatures should be used for very moist grain than for drier grain. It is better to take a longer time, and use a lower heat to dry moist grain, than it is to run the risk of parching or burning the grain. Another disadvantage of drying too fast is that the grains may crack, which leads to more broken grains during threshing, or the outer layer of the grain may harden, which makes it less permeable to moisture.

Very moist or big seeds are best dried in two or more stages between which the product rests for a day. As a rough guideline the moisture content of the product should not be decreased by more than 5% during each stage. Beans that are dried too much are difficult to cook until tender.

4.3 The movement of drying air

Warm air is lighter than cold air. So heated air rises by itself (vertical air current). Opposed to this is the horizontal air current of the wind. These two natural air currents are not very powerful: their speed decreases quite quickly when they meet obstacles.

Thick layers of grain, tightly packed (often threshed) products and small products (such as wheat grain) offer more resistance to air currents than thicker layers, loosely packed (often not threshed) or big products (like maize cobs). So in the bush drier (see the following section, and figure 10) the product is spread on a horizontal rack in a thin layer (a few cm up to a maximum of 10 cm) for a threshed product, or

in a thicker layer (10 cm up to a maximum of 50 cm) for a product not threshed.

When drying in the wind the product lies or hangs in a not too thick layer (10 to a maximum of 60 cm), perpendicular to the prevailing wind direction and preferably on a terrain exposed as much as possible to the wind. The air current can be improved a lot by drawing in air with a ventilator (motor drier).

An air current always chooses the path of least resistance. So the heated and/or blown air should not be allowed to escape before it has been brought in contact with the product to be dried. Also make sure that the resistance of the product to the passing air current is the same everywhere by hanging or stacking the product uniformly: an equal packing density and an equal thickness throughout.

A faster air current through the products causes the moisture equilibrium between product and drying air to be reached sooner. Remark: when a product has been dried by heating, after drying it should be allowed to cool to ambient temperature before putting it into storage.

4.4 Drying methods

The choice of drying method depends among other things on the type of product to be dried, on the weather during the harvest period and on materials available.

Drying in a completely dry harvesting period

The product can be dried in a simple way with the help of the sun and wind:

- Drying on the stem in the field before harvesting. Offers no protection against birds, for example. There is danger that the grains will shatter.
- Drying after the harvest on various kinds of racks which allow free circulation of air (see figure 7). The principle is that the natural current of the dry air (the wind) is hindered as little as possible on the outside. This method offers very little protection against other dangers that threaten the product (insects, birds, rodents and theft).

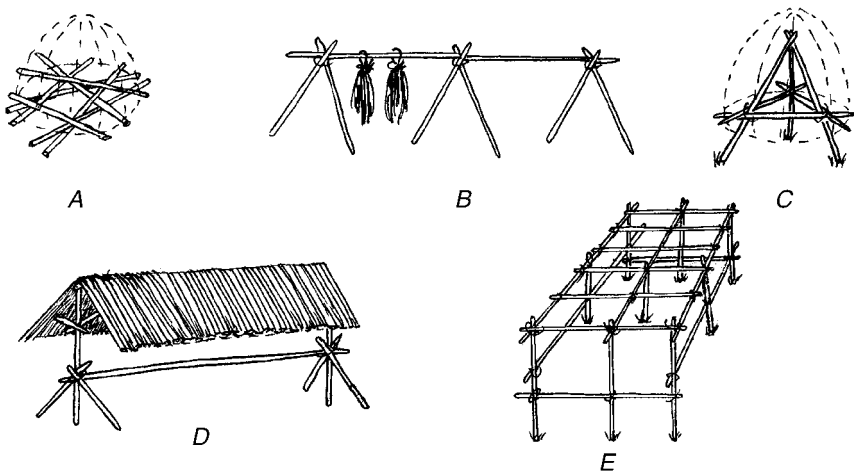


Figure 7: Different types of racks A: heap of branches on which cereals or beans can be dried, B: Rack on which bundles of product can be hung, C: Hay racks (tripod): a construction of poles on which a product can be stacked, D: Roofed rack, E: Drying platform..

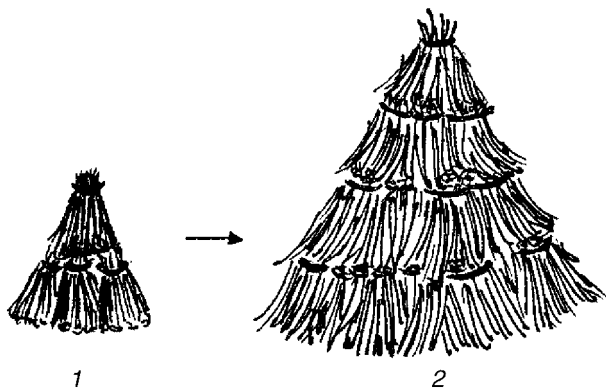


Figure 8: Stack of sheaved cereals.

Drying in a dry harvesting period with an occasional shower and cool nights.

It is very harmful for a product if it suddenly becomes wet again during drying. This will cause it to crack or burst. If the product is dried unthreshed the product should be on the inside and the foliage or straw as much as possible on the outside as extra protection against rain.

Methods:

- Drying on roofed racks where the wind reaches the product but the rain is kept out (figures 7 and 17).
- Drying in loosely built stacks (figure 8).
- The threshed product is spread out on a big piece of canvas in the sun (figures 5 and 6). During rain and at night the canvas is tied or folded together, and if possible brought inside. Because the product is directly exposed to the sun, the thin layer (eg. 3 cm) of grain should be evenly mixed every quarter of an hour or so. This method requires more attention but offers more protection against other dangers.

Drying in a wet harvesting period

- In a maize crib or in airy baskets (see storage methods 2 and 3). With this method the outside air, that should become drier soon after the harvest period, can blow through the unthreshed, loosely packed product as much as possible.
- Drying with the help of the flue gasses and the warm air of a fireplace (figure 9). This can be done for example by constructing an airy platform above the fireplace in such a way that the smoke and hot air can move easily through the product. Take care that sowing seed



Figure 9: Drying above the fireplace.

is not heated above 40 °C and watch out for fire. The costs are low and the method protects reasonably against the other dangers, but deterioration of taste may occur.

- A faster and more reliable, but more expensive way of drying is to bring artificially heated air in contact with the product to be dried. Two designs using oil drums in which a fire is made are presented here (figure 10 and 11): the simple oil drum drier and the pit barrel drier. The pit barrel drier is also known as the bush drier or Brooks fire drier. By making a fire in the connected oil drums the surrounding air is heated and rises through the product to be dried, which is spread in a not too thick layer on a screen, supported by logs, supported by logs.

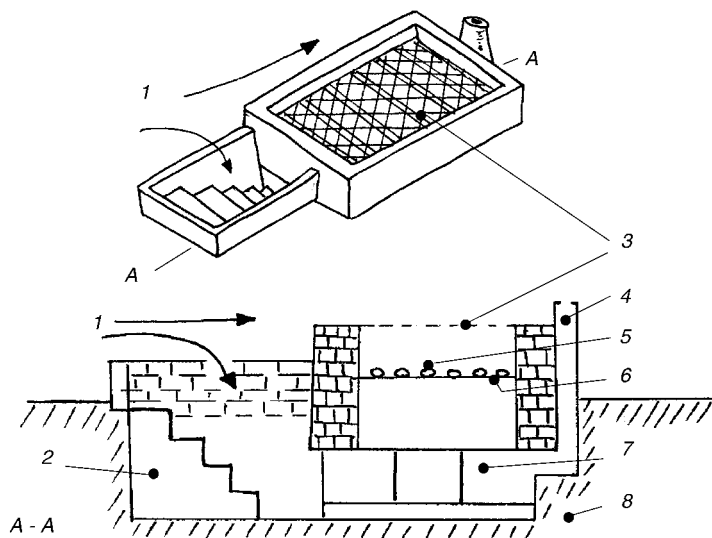


Figure 10: Barrel driers made out of barrels and hand-rammed earth or mudblocks. The pit barrel drier (A - A cross section). 1: wind direction, 2: stairs, 3: wire netting, 4: chimney, 5: logs, 6: floor ledge, 7: oil barrels, 8: soil.

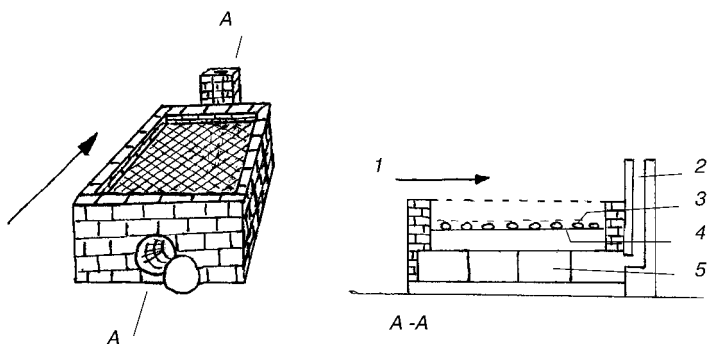


Figure 11: Barrel driers made out of barrels and hand-rammed earth or mudblocks. The sample barrel drier (A - A cross section). 1: wind direction, 2: chimney, 3: wire netting, 4: logs, 5: oil barrels.

Maximum thickness of layer: small grains, such as millet and sorghum 5 - 8 cm, shelled maize and other grains 10 cm, groundnuts 20 cm, maize on the cob 30 cm. As smoke may affect the taste of the product it is removed via a chimney situated downwind of the prevailing wind direction during drying. A shelter over the drier will protect it and the drying grain from rains. The fire should be watched constantly in order to prevent too high temperatures.

Limit the drying temperature for food grains to 50 - 55 °C. Do not dry sowing seeds in these driers as sowing seed should not be heated above 40 °C. Do not stir the drying grain; stir only to release the heat if overheating occurs.

The capacity depends on the product to be dried. For example up to 500 kg of shelled maize can be dried per day.

Construction materials: oil drums, chicken wire or other screen, iron rods, cement, iron wire, wooden logs. Operating costs consist mainly of the costs of fuel (firewood or maize cobs, rice husks etc.) which may be high, and labour. The construction requires accurate work. A construction manual is available on request from Agromisa.

- Solar driers. These have the advantage of no fuel costs and can also be used for other crops such as copra, cassava, fruits and vegetables. Disadvantages are:
 - temperatures may rise to 65 - 80 °C: rice and sowing seed can be damaged.
 - most useful only at certain hours of the day and of limited use during long periods of rainfall or very cloudy weather.

It is also possible to build a solar drier which can work on solar heat for most of the time, but which can, if necessary, be artificially heated during periods of heavy clouding or rain (see figure 12). A construction manual is available on request.

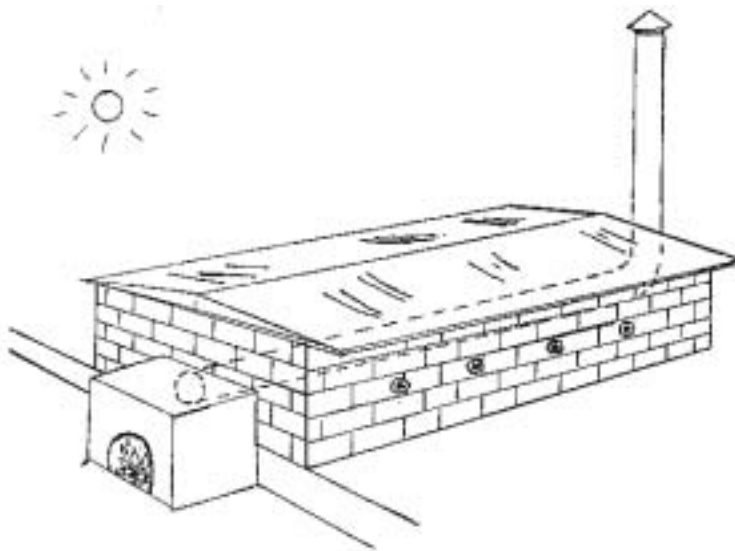


Figure 12: A dual purpose solar/ fuel heated drier..

- Motor driers (figure 13). A motor driven ventilator blows either heated cooling air of the motor or air heated by a burner through the product, which is spread on a drying platform.

At the International Rice Research Institute (Manila, Philippines) a batch drier for rice has been developed which can use the rice husks as fuel.

Motor driers are suitable for drying cereals, pulses and oil containing products. The drying capacity depends on the size of the drier and on the product to be dried. For example 1000 kg of rice may be dried in about 5 hours with the IRRI batch drier. Construction materials: an engine (for example 3 - 5 HP), a fan, wood, wire and a kerosene burner.

The costs of construction and of fuel may be a constraint for the individual farmer. Therefore it is better if it can be owned and used by a group of farmers. For construction accurate work and technical understanding is required. As mentioned before the fuel costs of barrel driers and motor driers may be a constraint on their use. Moreover, fuel is sometimes difficult to obtain. Therefore drying methods have to be adapted to local circumstances: climate, technical knowledge, availability of fuels and construction materials etc. If you are seriously interested you can submit your drying problems to Agromisa or the Royal Tropical Institute in the Netherlands. It is helpful if you can supply information about the product to be dried (type, amount, use etc.), climate during the drying period (amount of sunshine, rainfall, temperature etc.), availability of fuels and construction materials.

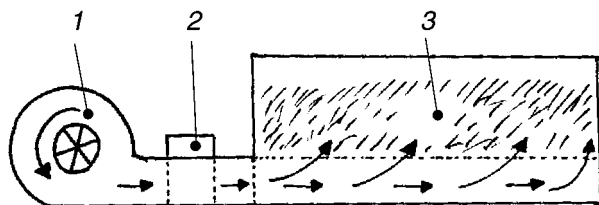


Figure 13: Principle of a motor drier. 1: ventilator, 2: burner, 3: product to be dried.

5 Storage methods

5.1 Introduction

Products can be stored in many different kinds of storage containers varying from earthen gourds, baskets, cribs and suchlike, to big metal or cement silos. Depending on financial possibilities, available materials and external circumstances (climate) one can choose from the storage methods mentioned below. Again it is emphasized that every storage container, no matter what it looks like or what it is made of, should keep the product dry and cool, and protect it against insects, fungi, rodents, domestic animals and thieves. A small part which is infested by insects or fungi or has a too high moisture content may spoil the whole amount. That is why in one storage container only uniform batches should be stored.

Temperature

It is of greatest importance that a roof is constructed above the silos in such a way that it extends far enough to protect the walls against full sunlight. This lowers the inside temperature, lessens temperature changes between day and night and reduces the chance of local heating, which causes condensation in other, cooler spots with consequent fungus growth. One can also use building materials which do not easily pass on changes in outside temperatures to the stored grains (good insulators), or one can paint the containers white.

Moisture

Moisture may enter the storage container via the ground, the walls or the roof. A good overhanging roof protects the walls against rain. In order to prevent moisture coming up from the ground, the gourds, baskets, sacks etc. should always be placed on a dry underfloor or on a platform of bricks or wooden poles. Floors of stone or concrete can be laid on a moisture barrier made of metal foil, tar paper, plastic and/or should have a waterproof layer of cement of 1 cm thickness (weight ratio water:cement:sand = 0.3:1:3).

During storage in the rainy season moisture from the air can also enter via the walls of the silo, unless this is taken into account when choosing and building the silo (airtight storage).

Insects

First of all it is important to keep the storage room and the surrounding area as clean as possible, especially when using a non-airtight storage method. Put a clean product into a container, only after all old products, dust, straw and insects have been removed, and all cracks and holes have been filled and sealed. One should distinguish between insects that are already present in the product to be stored and insects that may enter the storage room during storage.

Insects already present in the product.

Prevent further development of the insects by:

- Airtight storage (see below).
- Sunning. Insects leave grain which is placed in hot sunlight as they do not like temperatures higher than 40 - 50 °C. The sunning process, however, does not always kill eggs and larvae present inside the grain itself.
- Mixing the grains with wood ash (or ash of burned rice husks), burned cowdung, fine sand, lime, diatomaceous earth or certain types of kaolin clay. Volume ratios of ash:grain = 1:1 to 1:2, and clay:grain = 1:10. The effect of kaolin clay is greatly enhanced if sulphuric or hydrochloric acid is added and subsequently heated to 400 °C.

The materials used, fill the spaces between the grains, thereby restricting insect movement and emergence. A similar method is the admixture of small cereal grains, for example millet, with maize or sorghum. Certain vegetable oils, such as palm and groundnut oil, applied to pulses, give protection against bruchids (a kind of beetle).

- Mixing local plants with the grains.

In many areas local plants are known of which the roots, leaves, flowers and/or fruits (dried and ground) act as a repellent or in-

secticide (for example neem leaves, sweet flag, derris). Ask the local people!

- Smoking the product.
The smoke and heat of the fire kills and drives insects out of the product to be stored (see also chapter 4).
- Storing unthreshed grains or beans gives some protection against insect attack (see also chapter 3).
- Use of insecticides such as lindane, malathion or pyrethrum. Remember that insecticides are also poisonous for humans and animals and therefore should be used with care and according to the instructions given.

Insects that may enter the storage room during storage.

They can be prevented from entering by constructing the silo well. Well closed fill- and outflow-openings prevent this type of infestation. Baskets may be smeared with mud to seal them. One can prevent infestation through insects such as ants and termites by building a silo on poles which:

- are treated with Paris green, coal-tar or green camphor oil
- are surrounded by a layer of sieved wood ashes
- are covered with fat or waste oil. Also waste oil can be poured into the holes before the poles are put into place.

Rodents

Mice and rats should be combatted by closing all holes in the silo or fitting these with fine-meshed wire netting, or by building the silo on poles, at least 75 cm high, with rat baffles around the poles (figure 14). If the silo is under a tree, rodents may jump from the tree and enter the silo via the roof.

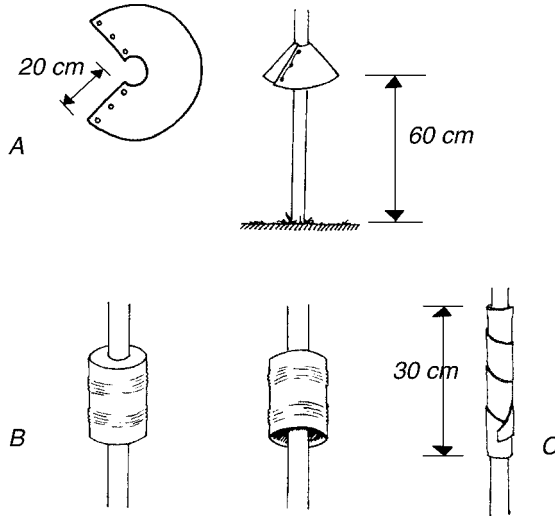


Figure 14: Examples of rat baffles. The baffle must fit tight to keep even the smallest rodent from climbing between the baffle and the pole. A: metal collar, B: metal can upside down, C: metal band around the post.

Domestic animals

These can be kept away by building a fence around the silo, made out of wood, bamboo or other local materials. A stack of twigs around the silo is also sufficient. Take care that it does not become a hiding place for rats.

Thieves

Theft is made more difficult if the fill- and outflow openings are made in such a way that they can be locked. It is also possible to construct a silo without an outflow.

Airtight and non-airtight storage

Storage methods can be divided into airtight and non-airtight storage. Airtight storage can be achieved using pots and gourds that are varnished or treated with linseed oil, pitch, bitumen or any thick substance

which will stick to it. Other airtight storage methods include plastic bags, the Pusa bin, oil drums, metal silos, underground pits and brick or concrete silos which are specially treated with waterproof mortar or waterproof paints. The lid and outflow-opening, if present, should be covered with rubber or sealed with mud, cowdung, tar or wax.

The advantages of airtight storage are:

- Cheap insect eradication. On account of the respiration of the stored product (unless it is very dry) and of the insects present, oxygen is used and carbon dioxide is formed which results in the death of the insects. In order to accelerate this process, at the top of the silo a piece of candle can be placed in a tin and lit just before closing the silo. The burning candle quickly uses a great deal of the oxygen present. It is important to fill the silo to the top, because then the oxygen present is used up faster.
- Moist outside air cannot enter. This is important in the humid tropics.

The disadvantages of airtight storage are:

- The crop should be well dried, as further drying during storage is impossible. In order to prevent fungus growth and decline in viability of sowing seed the moisture content of the stored product should not be higher than the safe moisture content (12 - 13% for cereals and pulses, approximately 7% for oil containing products). But grains with this moisture content can still be attractive to certain insects. Therefore the moisture level in grain has to be 9% or less to slow down insect development, unless other precautions are taken (see above).
- Completely airtight storage is difficult to attain (fissures, near the lid, tiny cracks in the wall etc.).
- When one regularly uses part of the stock for food the principle of airtight storage is lost, because every time the silo is opened fresh air enters. This is particularly so when the silo has to be opened from above. Silos with an outflow opening at the bottom retain the carbon dioxide layer on top of the product.

- Regular checking of the product is difficult, because the silo and its contents cannot be inspected completely without letting air inside.

As well as the above steps one should also:

- Repair the storage place. Fill and seal all cracks and holes. Paint or whitewash the walls and floors of the storage place. This helps close up very small holes (insects like these small holes).
- Clean the storage room or building thoroughly. Burn or compost all dust, old pieces of grain, dirt, straw etc. In silos made of bricks, concrete or mud burn the leftovers inside the silo: the ash and smoke work as disinfectants. Also clean the outside area around the storage place.
Organic material should be removed as this attracts insects and termites.
- Inspect the stored product weekly if possible (except for airtight storage).

Method 1: Earthen pots and gourds

Especially in the dry tropics, earthenware pots and gourds (the hard, dried outside cases of certain fruits or vegetables) are very useful for storing small quantities. They should be kept inside or under a shelter. Above the kitchen (a place where there are few insects) is a good place. By treating the pots and gourds with varnish, paint or linseed oil, and sealing the lids with mud or cowdung an airtight form of storage is obtained (also suitable for the wet tropics).

Note: big tins (for example milk powder tins) and wicker bottles are also suitable for storage.

Suitable for: small quantities of cereals, beans, groundnuts, and also for the storage of sowing seed.

Storage time: about one year

Contents: 5 - 30 litres

Costs: small

Method 2: Baskets

Baskets are especially usable in the dry tropics. In the humid tropics ventilation should be good, so don't put them close together. They should be raised off the ground on a platform. Place rodent baffles on the legs of the platform.



Figure 15: Traditional baskets.

Baskets do not give enough protection against insects, but this can be improved by applying mud, clay or cowdung to the in- and outside. The cover should be tight, and sealed with plaster of the same material. The same effect is obtained by using a plastic bag inside the basket, which also makes storage airtight. If a basket is plastered, further ventilation is made impossible. If then a too moist product is stored it will go mouldy and rot quickly. Therefore one has to decide whether priority should be given to further drying or to more protection against insects. The outside layer of mud also gives protection against rodents. With this storage method it is possible to use insecticides and with big baskets it is certainly advisable: dust the inside of the basket and mix the grain with insecticide. Wash it carefully before consuming it. If insecticide is not available mix burned cowdung or wood ashes with the grain. Make sure the basket is well-protected from the rain. If it is made of grass or reed keep it in the house or some other dry building.

Suitable for: cereals, pulses, oil containing seeds and potatoes
Storage time: 6 - 9 months
Contents: 25 - 2000 litres

Materials: reed, grass, wattle, palm leaves, bamboo etc.
Costs: material, low; labour, high

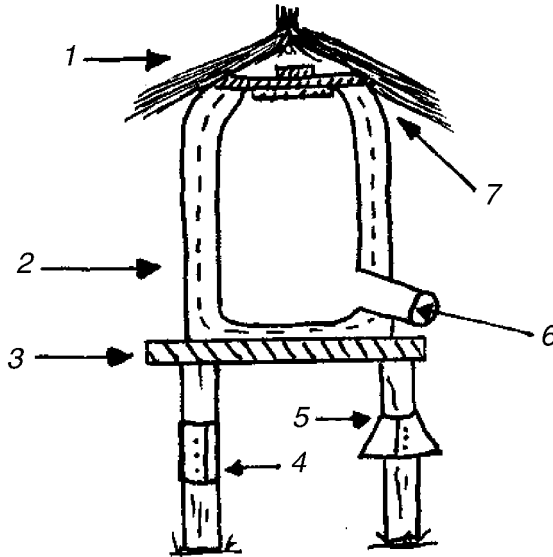


Figure 16: Diagram of an improved basket: plastered with clay and raised off the ground on a platform on poles. 1: traditional grass or reed thatch, 2: clay plaster inside & outside, 3: platform, 4 & 5: baffles on poles, 6: tin with press-on lid (e.g. coffee tin) with bottom removed. Set into wall to provide (insect proof) emptying spout, 7: wooden cover plastered in place and sealed with clay after granary is filled.

Method 3: Maize crib

The maize crib is suitable for the storage of maize cobs in the humid and dry tropics. The maize crib design of figure 17 has such a shape that the drying process continues during storage, because of natural ventilation. This applies to periods of low rainfall, during which the relative humidity regularly drops below 70%.

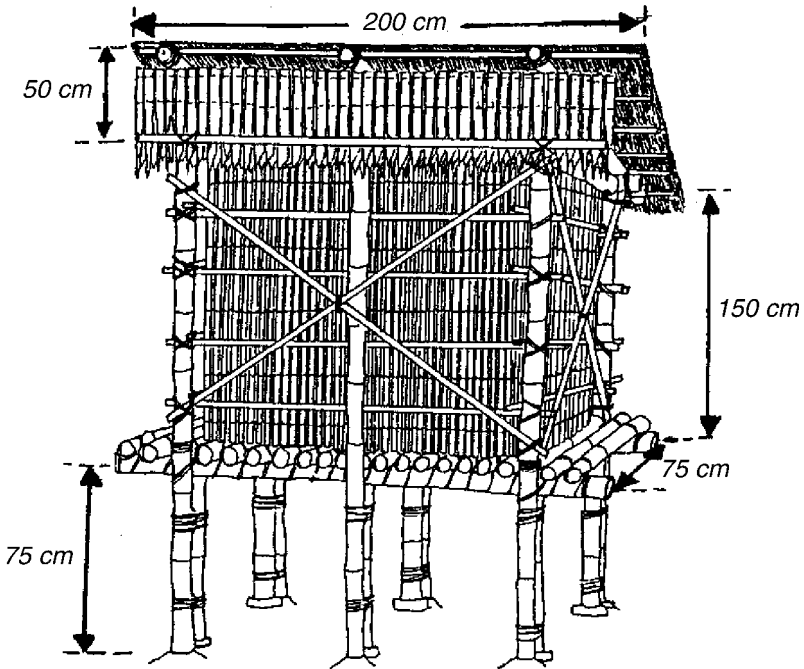


Figure 17: Maize crib made of bamboo.

The crib should be placed ideally with the long side perpendicular to the prevailing wind direction during storage. Because of the narrow shape (maximum width in the humid tropics is 60 cm) the drying process is better than in the traditional round crib. The maize crib offers very little protection against insects. Varieties with husks that

cover the whole cob (the traditional varieties) are protected reasonably well for 3 - 6 months.

If insecticides are to be applied the husks should be removed so that the insecticide can cover the whole surface of the kernels. The outer walls should also be dusted regularly, depending on how long the insecticide lasts, to prevent insects from entering. Removing the husks also accelerates the drying of the kernels. After the kernels on the cobs have reached the safe moisture content, they may be shelled off and stored in a less voluminous way.

The maize is not protected against thieves if it is stored in this way.

Suitable for: maize, yam

Storage time: 3 - 6 months without insecticides

Contents: 400 kg of maize cobs per metre length at a width of 60 cm and a height of 1.5 m. (400 kg maize on the cob = 270 kg shelled maize).

Materials: legs and side supports: bamboo or other straight poles
sides: split bamboo, palm leaf stems, raffia or other wood
roof: raffia mat or thatching grass

Costs: in general low, depending on the materials used

Method 4: Jute sacks

In general jute sacks are cheaper than sacks made of cotton or sisal. These sacks are especially suitable for the dry tropics. Because of the danger of moisture uptake they should not be placed on concrete floors or on the ground, but on plastic sheets, waterproof canvas or on wooden pallets. The latter method is preferred because it also allows air to flow under the sacks. Do not stack sacks against the walls, as insects and termites can get into the grain from the walls. Stack the sacks in a neat manner in not too big quantities on top of and against each other. Leave some space between the sacks so that air can move freely between them (see figure 18). Paths 40 cm wide should be left open between the stacks for inspection, cleaning and control of insects and rodents.

Advantages of fibre sacks are the following. The product can have a slightly higher moisture content than when put into airtight storage, provided the sacks are stacked in such a way that air can move through the sacks for continued drying and cooling. Sacks are easy to handle and label. These sacks allow gasses to pass through and therefore insects may be controlled by using fumigants in a closed room or underneath a plastic sheet covering the stack. **This must be done by an expert.**

The main disadvantage is that fibre sacks do not give much natural protection against insects, rodents, fungi and moisture. They are also easily damaged during transport and handling.

Insecticide can be mixed with the product and dusted on the sacks. When no insecticide is available the grain should be mixed with sand or ashes if possible.

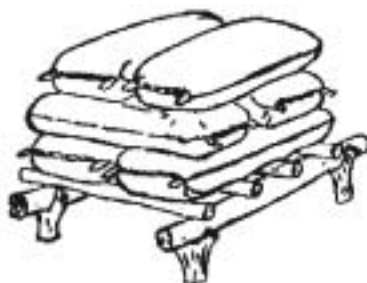


Figure 18: Pile of sacks on a pallet.

Before storing the product the storage place should be made insect- and rodent proof by sealing all holes and cracks with cement or mud. If the storage place needs ventilation the openings should be covered with mosquito wire.

Used sacks should be cleaned well and because of the possible presence of fungi in these old sacks, new sacks should be stored separately. To clean the sacks, first shake them well. If they are made of material which can be placed in hot water, boil the sacks or dip them in very hot water. Dry the sacks in the hot sun. If sacks cannot be placed in water, brush them well and place them in the sun. The sacks may also be fumigated in a closed container to kill insects.

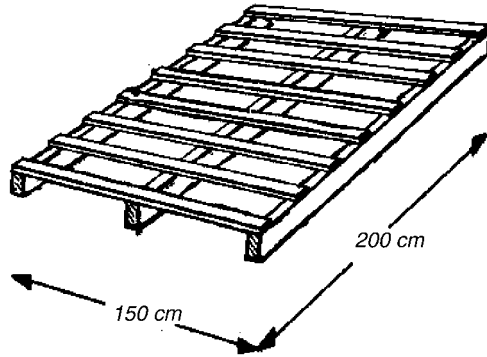


Figure 19: Pallet.

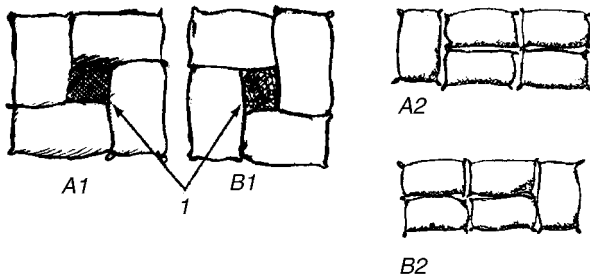


Figure 20: Stacking patterns for sacks on a pallet: Staple pattern for small stacks, A1: first layer, B1: second layer, 1: open space in centre for air circulation, A2: first layer, B2: second layer.

It is important to inspect and clean the storage place regularly (once a week). The collected dirt should be burned. Except for unshelled groundnuts it is not advisable to pile sacks in the open, because of the increased risk of insect attack. Infected produce should be winnowed, sieved and spread out in the sun before putting it in cleaned sacks again.

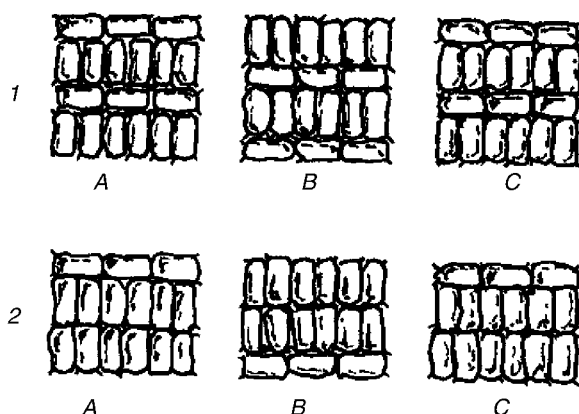


Figure 21: Stacking patterns for sacks on a pallet: Staple patterns for bigger stacks, 1: 3 bag unit, 2: 5 bag unit, A: first layer, B: second layer, C: third layer.

Suitable for: cereals, pulses, oil containing crops, potatoes
 Storage time: up to a year, depending on conditions
 Contents: 50 - 100 litres
 Materials: jute, sisal, cotton, hemp or other locally available fibres
 Costs: depending on local conditions

Method 5: Plastic bags

Plastic bags are suitable for storage in the humid and dry tropics. The product has to be dried well because during storage further drying is impossible. Even in open plastic bags the product does not dry because there is no air circulation. If the plastic bags are closed well (figure 22), airtight storage is obtained with all its advantages and disadvantages.

Plastic bags do not offer much protection against rodents so extra attention is required. Also certain seeds, such as some varieties of maize, have sharp points that can perforate the plastic. If the stored product is to be marketed and a lot of transport is involved, plastic bags are too weak. This depends, of course, on the thickness and strength of the plastic. If beans infected with dried-bean beetle or cereals infected with grain weevil are stored it is possible that the insects will puncture the plastic when trying to escape from the bag. This can be prevented by putting a bag of tightly woven cotton inside the plastic bag. Plastic becomes weak or brittle after continued exposure to ultra violet light, therefore no plastic package will last indefinitely in direct sunlight.

An advantage of transparent plastic is that the product remains visible, which makes checking the contents easier. Although the product may look alright from the outside, its quality may be disappointing when it is felt by hand, or it may be musty. A disadvantage of transparent plastic is that lizards can see insects which may be moving about inside, and may snap at them, which will damage the plastic.

Suitable for: sowing seed, cereals, pulses, groundnuts, copra
Storage time: 6 - 9 months
Contents: 50 - 100 litres
Costs: fairly high, except if good quality bags can be used eg. fertilizer bags

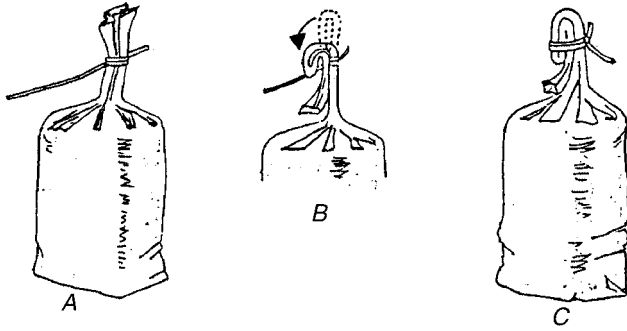


Figure 22: Closing the plastic bag to make it airtight. Fold up (B) the surplus plastic and then bend the fold back on itself (C).

Method 6: Earthen silos

Storage in earthen structures is often practised in the dry tropics. They are less suitable for the wet tropics because moisture may enter via the walls, which increases the chance of fungal growth. The walls of earthen silos can be made more waterproof in the following ways:

- 1 using a mixture of 90% loam or clay and 10% cement for construction of the walls.
- 2 painting or coating the outer walls with coal tar, asphalt, organic oils, water-repellent paints, resins etc.
- 3 applying a layer of waterproof mortar to the walls (weight ratio of sand: cement:water = 3:1:0.3), and painting them with coal tar or suchlike if available.

Whitewashing the walls helps to keep the silo cooler inside and closes up any small cracks or holes.

The product to be stored should be well dried before putting it in the silo as further drying is impossible. Earthen silos give better protection against insects than for example the maize crib, although it is still advisable to apply insecticide or fine sand etc. The silo should be protected from rain as heavy rains may cause severe damage.

The advantages compared with stone or concrete silos are that they are cheap, can be built with local materials and skilled labour is not needed.

The disadvantages are:

- moisture uptake from a humid environment, unless certain precautions are taken (see above).
- during drying up cracks often appear in the walls. This can be improved by mixing the mud with chopped straw or grass or by constructing a bamboo frame first and smearing that with mud.
- the lifetime is relatively short.

Suitable for: cereals, oil crops, pulses and yams
 Storage time: 6 - 9 months
 Contents: 0.5 - 2 tons
 Materials: clay or mud, bamboo or wood, and straw or grass for traditional types
 Costs: low, except for improvements
 Construction: simple

Figure 23 shows an improved mudblock silo. It is made of mud bricks and is improved by plastering and painting the walls. A construction manual is available on request.

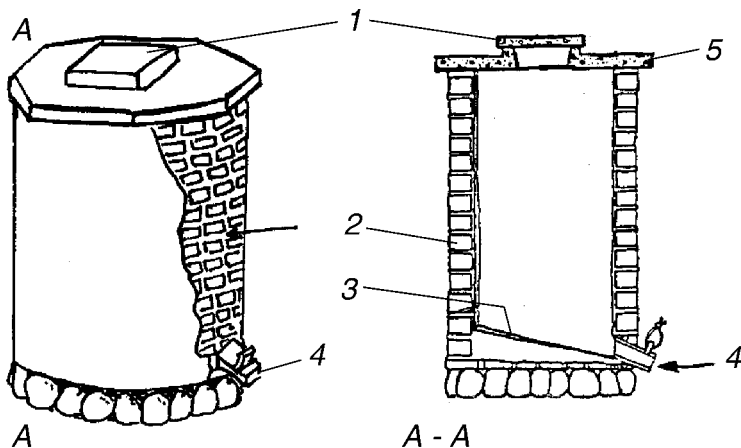
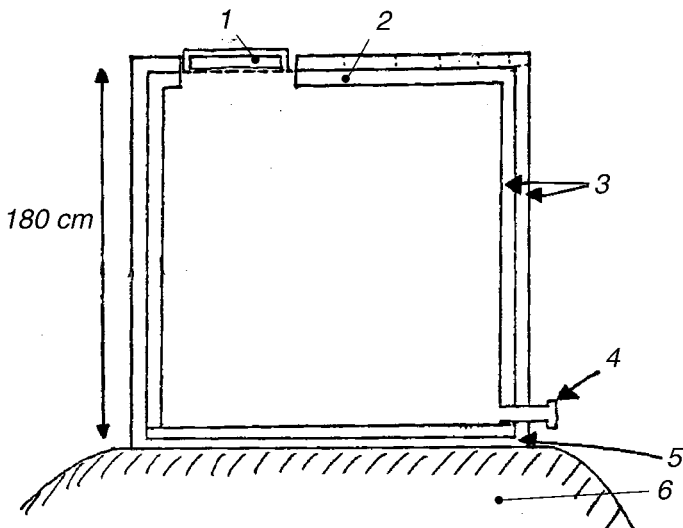


Figure 23: Improved mud block silo. 1: manhole cover, 2: mud block wall, 3: slanting floor to grain chute, 4: grain chute, 5: top slab. A - A: cross section.

Method 7: Pusa bin

The Indian Pusa bin is a square silo, double-walled all the way round - including the floor and roof - with a separating layer of plastic sheet between the walls. The plastic protects against moisture and keeps air from entering the stored product, provided the fill- and outflow openings can be tightly closed. The walls are made of mud blocks, but can also be made of mud (90%) mixed with cement (10%), fired bricks or concrete.

It is suitable for the dry and wet tropics, provided it is protected from rain. It gives good protection against insects and rodents, especially if the bottom 50 cm of the outside walls and the bottom layer are made of fired bricks or concrete.



*Figure 24: The Pusa bin (cross section). 1: fill opening with cover 60 * 60 cm, 2: mud slabs, 3: double walls of 7 cm mud, with plastic in between, 4: outlet, 5: bottom layer of fired bricks or concrete with sheet metal below, 6: firmly tramped down earth.*

- Suitable for: cereals, oil crops and pulses
- Storage time: 6 - 12 months. Very well dried crops (eg. wheat with a moisture content of 7.5%) can be kept for a couple of years.
- Contents: 400 - 3000 kg of cereals
- Materials: mud, cement or concrete, wood, mortar and plastic 1.8 m wide; pieces of plastic can be sealed together with an iron between two layers of paper.
- Costs: depending on the materials used; mainly the costs of 9 m² of plastic.
- Construction: A construction manual is available on request. The construction requires very accurate work.

Method 8: Metal drums

If metal drums (water tanks or oil drums) are available, they can be used for storage after cleaning them well. The drums should never be placed in direct sunlight because of the dangers of the product becoming caked to the inside wall, of moisture changes and heating of the stored product. They should either be placed under a good roof or should be insulated with a layer of straw. They can be used in the dry and humid tropics. In warm, wet places the drums may rust quickly unless precautions are taken. If they are airtight when closed it is possible to combat insects without using insecticides (see chapter 4).

Suitable for: cereals, pulses, sowing seed

Storage time: up to one year

Contents: depending on the size of drum, 50 - 200 litres

Costs: depend on local circumstances

Method 9: Small metal silos

For small metal silos the same applies as for metal drums. The content is bigger though, and can be up to about 5 tons.

Figure 25 shows an example of a metal silo which contains 3 tons. This model is made of sheet metal, 1 mm thick, welded together at the seams. This welding requires some skill, especially if the silo is to be airtight. It has two openings, one for filling at the top and one for emptying at the bottom. Like metal drums, metal silos should never be placed in full sun. A good overhanging room is the best solution.

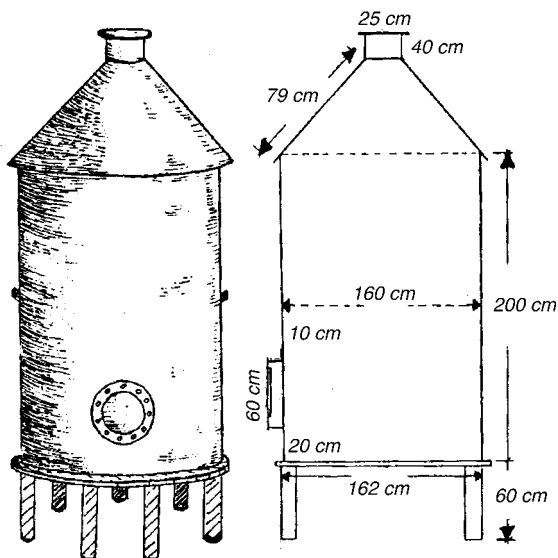


Figure 25: Sheet metal silo (3 tons).

Suitable for: cereals and pulses

Storage time: about one year

Contents: depends on the size

Materials: the 3 ton type requires 16 m² sheet iron, 1 mm thick

Costs: material and welding costs

Method 10: Brick and cement silos

These silos are suitable for both the dry and the wet tropics. They should be protected from rain by a roof and by a bottom floor made of (reinforced) concrete or (fired) bricks. The silos can provide air- and watertight storage if they are painted with for example chlorinated rubber-base paint, coal tar or bitumen. Brick and ferrocement silos can be built in many forms and sizes. Four types will be mentioned here:

- 1 the brick silo (figure 26)
- 2 the cement stave silo (figure 27)
- 3 the Thai ferrocement silo (figure 28)
- 4 concrete multicelled silos (figure 29)

Construction manuals are available on request.

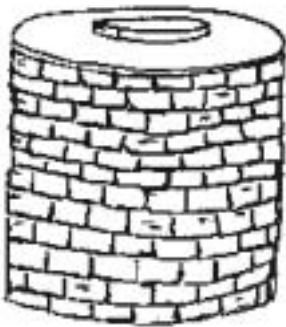


Figure 26: Brick storage silo.

The brick silo

The brick silo is made of mortared concrete (sandcrete) bricks placed on a reinforced foundation. The cover with a manhole is made of concrete or, if available, of sheet metal for ease of handling. It is quite easy to build.

Suitable for: cereals and pulses
Storage time: up to one year
Contents: 3000 litres (ca. 2100 kg)
Materials: cement (7 bags), reinforcing rod (36 m), wooden mould, (sheet metals)

The cement stave silo

This type of silo is more durable than the previous one. Because of the materials used it is more expensive, but less expensive than a sheet metal silo of the same capacity. It can be built raised on brick-made

pillars or on a brick layer foundation. The walls are made of cement staves, pressed together with iron wire, and the cover slab is made of concrete. The construction requires accuracy and some skill.

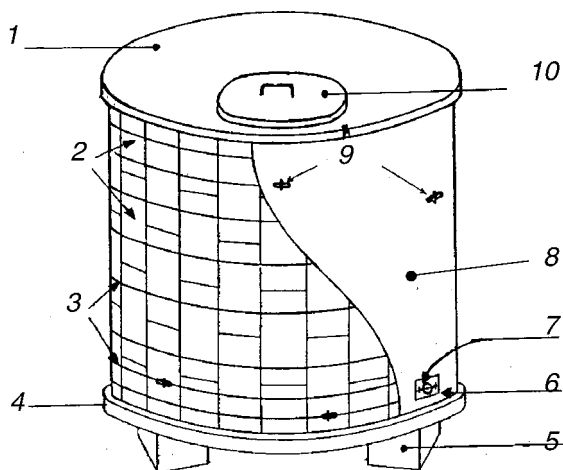


Figure 27: Cement stave silo. The 4.5 ton type has an interior height and an interior diameter of 2.0 meters. 1: cover slab, 2: staves, 3: wire, 4: floor slab, 5: pillars, 6: anti-theft device, 7: emptying-hole cap, 8: plastering, 9: wire tighteners, 10: manhole cover with handle.

| | | |
|----------------------------|--|--------------------|
| Suitable for: | cereals and pulses | |
| Storage time: | 9 - 12 months | |
| Contents: | depending on the size: 2.5 or 4.5 tons | |
| Materials: | 4.5 ton silo | 2.5 ton silo |
| ➤ cement (50 kg bags) | 12 bags | 9 bags |
| ➤ reinforcing rod (Ø 6 mm) | 8 bars (6 m) | 4 bars |
| ➤ galvanized wire (Ø 3 mm) | 1 roll (4 kg) | 0.5 roll |
| ➤ wire tighteners | 10 | 10 |
| ➤ coal tar | 15 l | 12 l |
| ➤ tar paper | 1 m ² | 1 m ² |
| ➤ gravel | 0.6 m ³ | 0.4 m ³ |
| ➤ sand | 2 m ³ | 1.5 m ³ |

The Thai ferrocement silo

Ferrocement is a kind of reinforced concrete. It is made of wire mesh (for example chicken wire), sand, water and cement. It is strong and durable. Ferrocement silos can be made in almost any shape. The Thai ferrocement silo shown in figure 28 has a conical shape and is waterproof and airtight. The base is saucer shaped and is made of two layers of reinforced concrete with a layer of bitumen, asphalt paper, plastic or metal foil in between. The frame of the walls is made of water pipes or bamboo poles and reinforcing rods, which support inside and outside layers of wire mesh.

The mesh structure is filled and smeared with mortar of a paste-like consistency: 1 part of standard cement, 1.75 parts sand with the optional addition of a plasticizer to improve workability. Water:cement ration is approximately 0.3 by weight. Ferrocement should be cured adequately: it must not dry too fast and should be kept moist and protected from the sun and wind for at least 5 - 7 days.

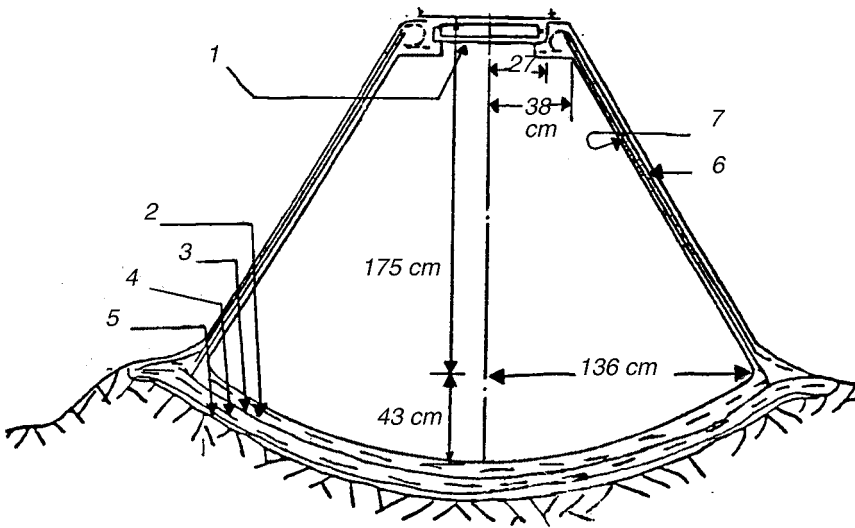


Figure 28: The Thai ferrocement silo (cross section). 1: manhole, 2: reinforced concrete, 3: sealant, 4: reinforced concrete, 5: mortar (foundation layer), 6: exterior mesh, 7: interior mesh.

- Suitable for: cereals and pulses
 Storage time: 9 - 12 months
 Contents: 4 - 6 tons, depending on the size
 Materials: for 3.5 tons of paddy or 4.5 tons of maize:
- cement 1000 kg
 - sand 1725 kg
 - aggregate 965 kg (used in the base)
 - mortar plasticizer 2 kg
 - sealant for base 5 kg (bitumen)
 - paint 0.75 kg
 - chicken wire 2 rolls
 - no. 2 rod 80 m
 - water pipe 32 m (19 mm diameter)

If bamboo poles are used instead of water pipes the walls have to be much thicker, requiring more cement.

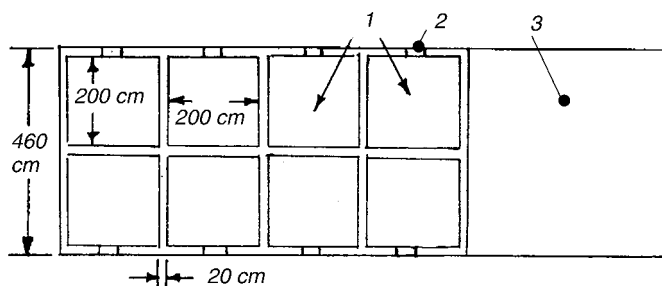


Figure 29: Concrete block square silos for co-operative storage. 1: storage cells, 2: fill and outflow openings, 3: drying, weighing, and office area.

Concrete multicelled silos

Many farmers form cooperatives and store their products collectively in large bins. Multicelled silo storage is an alternative to the larger, round silos. Each cell has an inside diameter of 2 m x 2 m x 2 m, and its own fill- and outflow openings.

Method 11: Underground pits

Pit storage is traditionally done in many areas in the (sub)tropics. Pits are generally easy and cheap to construct, provided there is a sufficient depth of workable soil. They are particular use in dry areas where wood and grass suitable for other forms of stores are in short supply. Traditional pits are to some extent protected from insect attack (through reduced oxygen levels) and rodents, although termite damage can be a problem. Also mould damage often occurs, especially around the pit sides and the surface of the product. Successful pit storage therefore depends on restricting the supply of air and moisture moving into the pit from the surrounding soil or from the atmosphere. Pits also provide a hiding place from thieves.

Traditional lining of pits is done with plant materials, such as grass, straw, chaff, maize stalks or sorghum and/or clay, cowdung or termite mound soil which is usually "fired" to harden the surface. The use of plant materials on their own probably does little more than prevent the grain from coming into contact with the soil, unless applied very thickly. The use of clay etc. may also restrict water entry, but does not prevent it entirely. The pits are closed and sealed with plant materials and soil, or with stones, sticks or bark, usually plastered

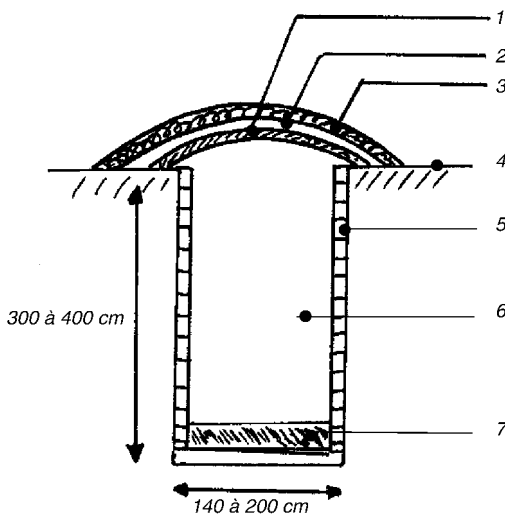


Figure 30: Traditional underground pit. 1: mud plaster, 2: dry soil, 3: straw, 4: soil level, 5: stone wall made with mud, 6: cereal / grain, 7: straw.

over with fresh cowdung. Pits may be cylindrical, rectangular or narrow-necked and may be placed in raised ground, under dwellings or beneath puddled clay or dung layers to prevent penetration of water.

Pit improvements

The roofing of the pit can be made of metal sheeting, sealed with mud/dung or bitumen, or polythene sheeting. A temporary shelter over the pit site gives protection from rain but should be removed in the dry season to ensure drying by evaporation, because a shelter does not prevent lateral movement of water into the pit.

Improving pit linings

- Coating the walls of the pit with a mud/dung/straw mixture. The grain remains much drier than in unimproved pits.
- Straw and mat lining: floor and walls are lined with a layer of straw covered with mats made of bamboo or grass. It does not protect as well as the following methods, but still is a potentially good method of reducing mould damage at least in short term storage.
- The product is put into well-sealed plastic bags, which are placed in the pit. Advantage: part of the product can be removed without letting air and moisture into the rest of it.
- Plastic lining: the pit is lined with plastic sheet or cut-open plastic which are sealed together. Disadvantage: the plastic lining can easily be damaged.
- Ferrocement lining (figure 31). A pit can be made air- and water-tight by using ferrocement to line the pit: two layers of mortar (cement:sand 1:3 with as little water as possible to make a paste), 2.5 - 3 cm thick, with a chicken wire reinforcement between the layers. The pit can be made water-tight by incorporating a bitumen layer between the two mortar layers or by applying a cement/bitumen emulsion layer as a final lining. A construction design is available on request.

Remarks

- Before filling an underground pit the inside of it has to be dry. Drying can be done with the aid of sunshine or by burning a fire inside (be careful of suffocation).

- As little air space as possible should be left inside and therefore the pit should be filled completely and preferably with a threshed product.
- When opening a pit one must wait half an hour before entering it: the lack of oxygen can cause suffocation.
- Ferrocement: the mortar should be cured adequately: it must not dry too fast, and should be kept moist and protected from the sun and wind for at least 5 - 7 days.

Suitable for: cereals and pulses

Storage time: depending on air- and watertightness and on local circumstances. The ferrocement-lined pit can store threshed grain for up to several years.

Capacity: depending on size, from 0.5 - 7 tons

Material: depends on lining and roofing materials used

Costs: low for a simple type

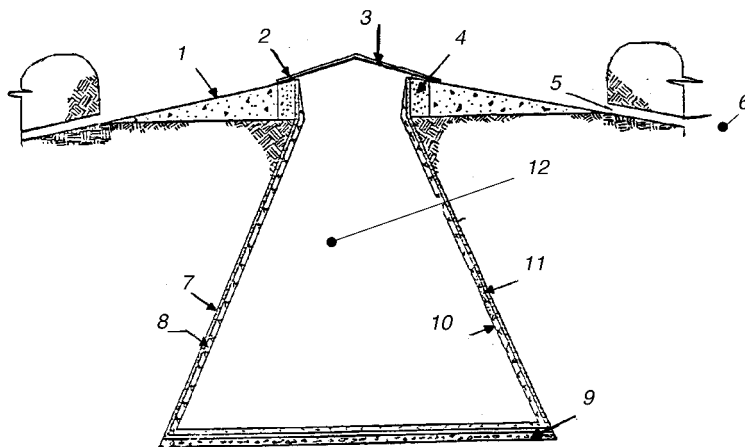


Figure 31: The improved ferro cement lined underground pit (cross section). 1: concrete 'lip', 2: sealant, 3: metal or concrete lid, 4: ring of stones to raise mouth, 5: drain pipe, 6: soil level, 7: first layer of mortar, 8: chicken wire, 9: hard core, 10: bitumen applied here, 11: second layer of mortar, 12: storage chamber.

Method 12: Clamp storage

Root crops, especially cassava and sweet potatoes are often cured and stored in field clamps. The basic design of these field clamps is as follows: a circular bed of straw or other material such as dried grass or sugar cane leaves, (approximately 1.5 m in diameter and 15 cm thick after it has been compacted) is placed on suitable, well-drained ground. The freshly harvested tubers are heaped in a conical pile of 300 - 500 kg on this straw bed. The pile is then covered with similar layer of straw and the entire clamp covered with soil to a thickness of 15 cm. The soil is then removed from around the circumference of the clamp, forming a drainage ditch (figure 32). During cool, moist periods this basic clamp design is satisfactory.

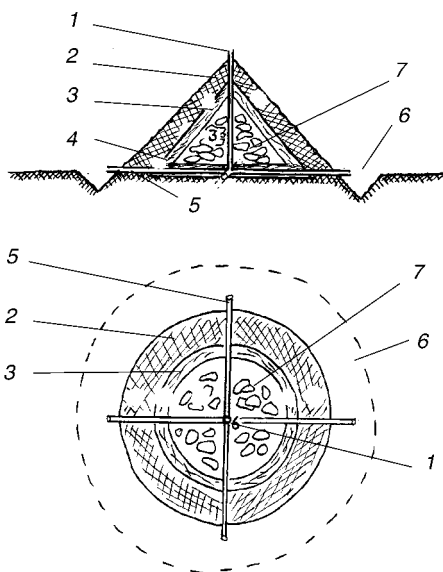


Figure 32: Design of (cassava) storage clamps. 1: central vertical ventilator, 2: soil covering layer (10 - 40 cm), 3: straw covering layer (5 - 15 cm), 4: basal straw layer (5-15 cm), 5: basal radial ventilators, 6: surrounding drainage ditch, 7: conical pile of cassava roots (300 - 500 kg), 8: ground level.

In order to prevent too much exposure to the sun or damage by heavy rains the clamp may be protected by a thatched shed or placed under a tree. In hot, dry conditions it is necessary to ensure that the internal clamp temperature does not exceed 40 °C, since tubers deteriorate rap-

idly at higher temperatures. The clamp can be altered for these conditions by incorporating the following modifications:

- a thicker soil cover to reduce internal temperature
- the construction of central and basal ventilators so as to encourage air flow within the clamp. Ventilators may be constructed from locally available materials, such as straw, hollow bamboo, drainpipes or timber. When basal ventilators are used, precautions should be taken to prevent the entry of mice and rats (for example by using wire netting).

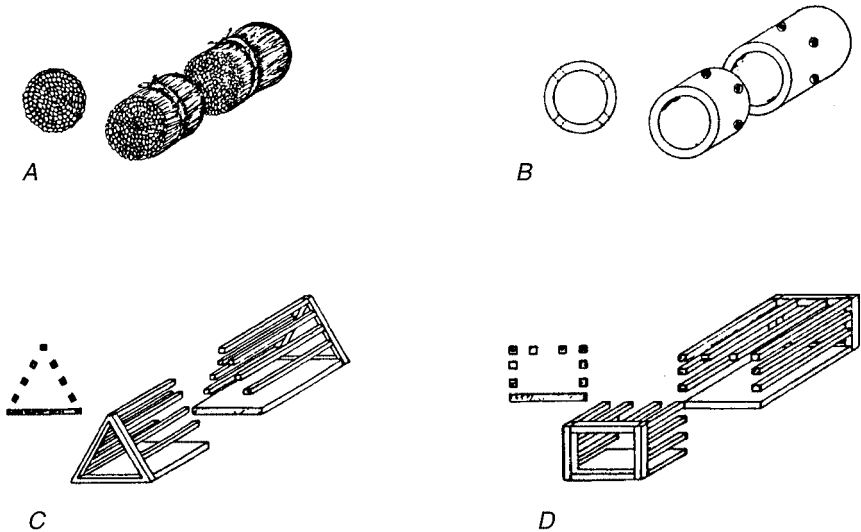


Figure 33: Various ways to make ventilators for (cassava) storage clamps. A: straw bundle, B: hollow tube with lateral holes (drain-pipe, bamboo), C: triangular frame (wood, bamboo), D: rectangular frame (wood, bamboo).

In very wet conditions, precautions need to be taken to prevent the roots from becoming wet during harvesting and handling, as well as within the clamp, since wet tubers deteriorate rapidly. Frequent, light rainfall tends to be advantageous after clamp construction, however, since moistening of the soil lowers the internal temperature of the

clamps. Therefore wetting the soil cover during hot, dry periods should be considered.

If more than 500 kg are to be stored in any one day, it is advisable that several circular clamps or a single elongated structure be built, since construction and internal temperature control are more difficult. Likewise this reduces the chance of the whole stock rotting, and being lost. It should be noted that before any specific clamp storage recommendations can be made, simple trials using locally available materials need to be undertaken during the required storage season in order to determine the best design and location of clamps. For clamp storage of cassava, interlayering with cassava leaves and/or replacing the straw cover by cassava leaves and later by coconut fronds seems to give better results.

Suitable for: root crops, especially cassava and sweet potato

Storage time: 2 - 9 months, depending on local conditions and type of root crop

Contents: up to 500 kg per (field) clamp

Costs: small, much work

Method 13: Storage in (ventilated) huts

The objective of this type of storage is to offer protection against rodents, sun, rain and groundwater, and to prevent fungus growth and rotting by means of ventilation. As this method offers hardly any protection against insects (unless great amounts of insecticides are used), it is less suitable for long-term storage of both threshed and unthreshed cereals and pulses. This storage method is well suited for the storage of root crops (see also chapter 3.4).

Locally available materials should be used for construction: bamboo, wooden boards (planks), woven mats in a wooden frame etc. For protection against rats and termites the huts can be built on poles at least 75 cm high with rat collars fixed on them. If building on the ground all holes and cracks should be closed with wire netting. If the walls are made of planks they should overlap like roof tiles with some space between them so that sunlight cannot enter but ventilation is still possible. The roof of wood or thatch should be overhanging for protection against sun and rain. Inside the hut the tubers should be piled in boxes or on shelves or racks along the wall in such a way that air can move freely between them. The contents should be checked regularly to make sure rotting is not taking place.

Further reading

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Useful addresses

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ICRISAT

International Crops Research Institute for Semi-Arid Tropics
Head Quarters: Patancheru, India

ICRISAT's mission is to help the poor of the semi-arid tropics through 'Science with a Human Face' and partnership-based research and to increase agricultural productivity and food security, reduce poverty, and protect the environment in SAT production systems.

<http://www.icrisat.org>, icrisat@cgiar.org

IITA, International Institute for Tropical Agriculture

Headquarters: P.M.B. 5320, , Ibadan, Nigeria

IITA conducts research, training, and information exchange activities. The research agenda addresses crop improvement, plant health, and resource and crop management within a food systems framework. Research focuses on smallholder cropping and post-harvest systems and on several food crops.

<http://www.iita.org>, IITA@cgiar.org

INPhO, Information Network on Post-harvest Operations

see also GATE-GTZ

To assist in preventing the loss of millions of tonnes of cereals, roots, tubers, fruits and vegetables in developing countries caused by inadequate handling and storage, pest damage, and transport and marketing problems the **INPhO** was set up in 2001. **INPhO** is led by the Food and Agriculture Organization of the United Nations (FAO) in partnership with GTZ and CIRAD. The project is supported by many international and national institutions dealing with post-harvest operations.

<http://www.fao.org/inpho/>, inpho@fao.org

IRRI, International Rice Research Institute

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ITDG, Intermediate Technology Development Group

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PTC+ is an international training institute, which focuses on all the links in the production chain on plant and animal commodities, (agricultural) technology, (food) technology and natural areas.

Training programmes are practice-oriented and mix theory with practical classes. **PTC+** offers “open entry” programmes, “tailor-made” programmes and consultancy. Programmes are offered in the Netherlands and/or at location.

It is the policy of **PTC+** to search for partnerships and co-operation programmes with national and international institutions abroad.

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Appendix 1: Measuring relative humidity and moisture content

This appendix is meant for those who want to measure the moisture content of a product, or the relative humidity of the air. It must be mentioned, though, that the measurement of the moisture content requires at least accurate weighing equipment. Moreover, the higher the desired accuracy, the higher the requirements for the method and equipment used. Some methods will be discussed briefly. More information can be obtained from Agromisa.

Measuring the moisture content

As indicated in chapter 1 the moisture content of a product is usually expressed as:

$$\text{Moisture content (\%)} = \frac{\text{weight of water in the moist product}}{\text{weight of the moist product}} \times 100$$

This can also be expressed as:

$$\frac{W_m - W_d}{W_m} \times 100$$

Where:

W_m = weight of the moist product

W_d = weight of the (oven) dry product

The many methods of measuring the moisture content can be subdivided in direct and indirect methods. The **direct methods** measure the amount of water directly, while the **indirect methods** measure other characteristics of the product that depend on the moisture content (eg. the conductance of electricity). Indirect methods are less time-consuming than direct methods, but require expensive equipment. The direct methods are less expensive, but still require weighing equipment.

Three of the most simple (direct) methods will be described here

The oven method

Materials: weighing equipment, a (ventilated) oven with controllable temperature, a thermometer, ovenproof metal weighing dishes. A ground sample (ground for example with a coffee mill) is weighed (W_m), put in the oven at 130 °C for 1 to 2 hours, or at 105 °C for 16 to 20 hours, and weighed again (W_d). The moisture content is calculated with the above formula. The amount of sample to be weighed (W_m) depends on the accuracy of the weighing equipment and on the desired accuracy of the moisture content measurement itself. It ranges from 5 g for very accurate equipment to 100 g or more for less accurate equipment. Ideally the procedure should be repeated once or twice. During cooling and weighing the oven-dry sample must be covered with a lid in order to prevent moisture uptake from the air. If the oven temperature is too high, other components apart from water may evaporate, and consequently a too high moisture content is calculated. Therefore, the oven temperature must be kept under control.

The infra-red lamp method

Materials: an infra-red lamp or a very strong bulb (250 Watt) with fitting, weighing equipment, tin cans. The ground sample is weighed and placed in the can underneath the lamp. The heat transmitted by the lamp causes the water inside the produce to evaporate. After 10 - 30 minutes, depending on the product, the sample is weighed again. The moisture content is calculated from the formula. During the heating period the sample is carefully shaken one or two times to prevent caking of the product. Too high temperatures may cause burning (discoloration). Instead of one lamp, one can also use two to perform a simultaneous replication. The lamp and the tin can must always be arranged in the same way. The calculated moisture content should be verified using the oven method as a control.

The oil immersion method

Materials: vegetable cooking oil, thermometers, container (tall and/or with a narrow opening at the top), fitted with an iron wire to hold the thermometer, stove or other heating device, wire net, weighing equipment.

Weigh 100 g of sample and put it in the container together with the oil. A wire net above the seeds prevents them from spilling over during boiling. Use only enough oil to cover the seeds. The thermometer is inserted and the weight of the whole apparatus is measured. The whole apparatus is then heated on the stove until the temperature has reached 190 °C. Then the whole apparatus is weighed again. The difference in weight is equal to the amount of water in the moist product ($W_m - W_d$, of the formula). The weight of the moist product (W_m) is, of course, 100 g. Care must be taken during heating that the oil does not spatter out of the container.

Measuring the relative humidity of the air

As indicated in chapter 1, the relative humidity at a given temperature is expressed as:

$$\text{Relative humidity (\%)} = \frac{\text{amount of water vapour present in the air}}{\text{maximum amount of water vapour that air of that temperature can contain}} \times 100$$

Two other essential terms are the dry-bulb temperature and the wet-bulb temperature. The dry-bulb temperature (T_d) is the temperature of the air measured by an ordinary thermometer. The wet-bulb temperature (T_w) is the temperature of the air measured by an ordinary thermometer whose glass bulb is covered by a wet cloth or gauze (a cloth "sock" is slipped on to the bulb end of the thermometer and then dipped into water). The temperature is recorded after the thermometer has been moved rapidly (by shaking or rotating it) through the air.

A **sling psychrometer** has the two thermometers mounted on a base plate. The wet bulb extends below the dry bulb. The instrument is turned around two or three times per second until readings attain a constant value.

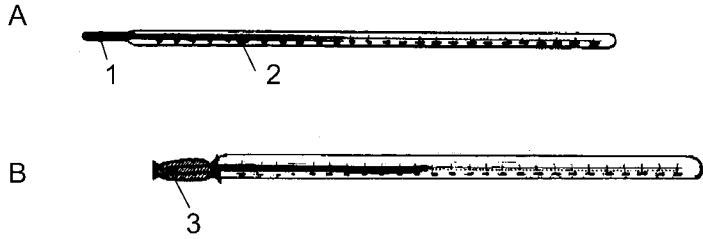


Figure 34: a: Dry bulb thermometer, b: Wet bulb thermometer. 1: bulb, 2: stem, 3: cloth wick.

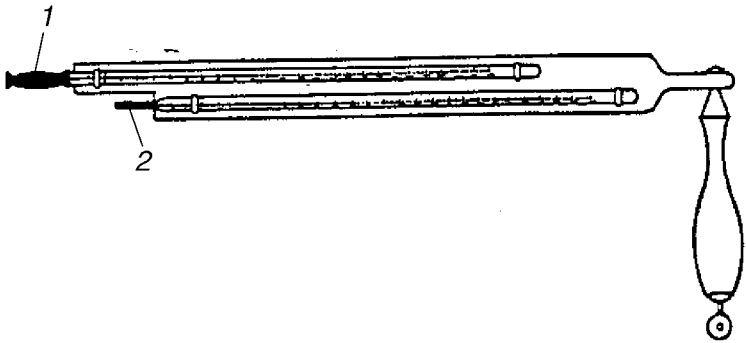


Figure 35: Sling psychrometer. 1: wet bulb, 2: dry bulb.

The wet-bulb thermometer indicates a lower temperature because the moisture which evaporates during the slinging cools the surface of the thermometer bulb. The difference in temperature between the two thermometer readings ($T_d - T_w = \Delta T$) is a measure for the relative humidity of the air at the temperature T_d . From the table below the relative humidities can be read when ΔT and T_d are known. For example: if the dry-bulb temperature is 25 °C (T_d) and the wet-bulb temperature is 22 °C, then ΔT is 3 °C, and the relative humidity of the air is 77%. Intermediate values can be estimated.

One requirement is, of course, that both the thermometers must indicate the same temperature when used as ordinary thermometers. Ide-

ally the thermometers should be read at a distance of an arm's length. If only one thermometer is available it can be used alternately as a dry-bulb and a wet-bulb thermometer, provided it is calibrated.

Table 5: Relative humidity, with known ΔT and T_d .

| Td | ΔT | | | | | | | | | | |
|----|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| | 0 | 1,0 | 2,0 | 3,0 | 4,0 | 5,0 | 6,0 | 7,0 | 8,0 | 9,0 | 10,0 |
| 5 | 100 | 86 | 72 | 58 | 45 | 33 | 20 | 7 | - | - | - |
| 10 | 100 | 88 | 77 | 66 | 55 | 44 | 34 | 24 | 15 | 6 | - |
| 15 | 100 | 90 | 80 | 71 | 61 | 53 | 44 | 36 | 27 | 20 | 13 |
| 20 | 100 | 91 | 83 | 74 | 66 | 59 | 51 | 44 | 37 | 31 | 24 |
| 25 | 100 | 92 | 84 | 77 | 70 | 63 | 57 | 50 | 44 | 39 | 33 |
| 30 | 100 | 93 | 86 | 79 | 73 | 67 | 61 | 55 | 50 | 44 | 39 |
| 35 | 100 | 94 | 87 | 81 | 75 | 69 | 64 | 59 | 54 | 49 | 44 |
| 40 | 100 | 94 | 88 | 82 | 77 | 72 | 67 | 62 | 57 | 53 | 48 |

Table 1 is a simplified table, valid for an air speed of approximately 2.5 metres per second, an air pressure of around 1 atmosphere (c. 1000 millibar), and no direct radiation of the sun on the wet bulb or on the thermometers.

Conversion of degrees Celsius to degrees Fahrenheit, and vice-versa (see figure 36) .

$$(^{\circ}\text{F}) = 9/5 \times (^{\circ}\text{C} + 32)$$

$$(^{\circ}\text{C}) = 5/9 \times (^{\circ}\text{F} - 32)$$

There is also equipment available to measure the relative humidity of grains stored in bulk (hair-hygrometer), but these are expensive.

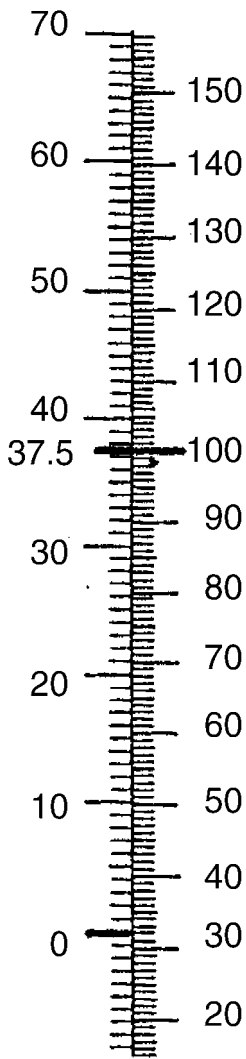


Figure 36: Conversion of °C and °F.