COURSE OUTLINE

1. Basic Principles of Crop Storage & Preservation.
2. Pest and Insect Infestations in Stored Products and Storage Structures.
3. Types of Storage Structures – Traditional & Improved Systems.
4. Design of Storage Structures for grains, Semi-perishable Crops (e.g., potatoes, yam, etc) and Perishable (e.g. fruits and vegetables).
5. Strategic Food Reserve.

BASIC DEFINITION AND INTRODUCTION

1.1 Basic Definitions

What is Storage and why storage?

Storage is the art of keeping the quality of agricultural materials and preventing them from deterioration for specific period of time, beyond their normal shelf life.

Storage is essential for the following reasons:

- Perishable nature of agric. & bio-materials
- Provision of food materials all year round
- Pilling/ provision for large scale processing
- Preservation of viability for multiplication
- Prevention of original varieties from extinction (Germ Bank)
- Preservation of nutritional quality
- Weapon for national stability
- Price control and regulation
- Optimization of farmers' gain / financial empowerment of farmers
- Opportunity for export market, etc

Crop storage is an important aspect of post harvest technology. The original aim of storing agricultural product is to provide food between the harvest seasons and to provide seed for subsequent planting. Other aims of storage include orderly distribution and supply of produce throughout the year or a given period of time; preservation for unknown future of low productivity, and price control or stabilization. Storage has greatly helped farmers to run their farm at a profit. During harvest seasons, supply is higher than consumption and price falls. Storage also aims at reducing unnecessary field losses. Storage could also be a means of maintaining quality and a high nutritional value of food, especially cereal.

Typical storage facilities in the tropics mostly provide short term storage. This is because of the subsistent farming pattern and the quantity produced by individual farmer is small. The bi- modal rainfall pattern also contributes to the storage problem. The relative humidity is high at the period of harvest. Ibadan, for example, early maize is harvested between June and July while late maize is harvested between November and December.

The relative humidity during these periods is between 72 – 84% while the environmental temperature is between 26-30^{o}C. These climate conditions are not adequate for the traditional method of storage practiced by most farmers.

1.2 Nature of Agric./ Bio-materials in Relation to Storage

Agric./ bio-material have the following characteristics/ nature in relation to storage:

- Living organism
- Moisture rich
- Ripening process
- Bio degradable
- Hygroscopic: Shrinkage and swelling occur

2.0 CLASSIFICATIONS OF THE TYPES STORAGE

Classification of storage types can be based on the following factors:

- Duration of Storage
- Size or Scale of Storage
- Principle of Storage

2.1 Classification Based on Duration of Storage

Storage systems are classified in terms of duration of storage as:

- Short Term Storage
- Medium Term Storage
- Long Term Storage

Stored products in short term storage mostly do not last beyond 6 months. Highly perishable products (such as egg, meat, fish and dairy products) are naturally stored for short term. High loss of quality is associated with highly perishable crops in this storage except controlled systems are used.

Medium term storage involves keeping the quality of stored products without appreciable deteriorations for up to 12 months. The quality of such stored products may not be guaranteed after 18 months. Long term storage can guarantee the quality of stored products beyond 5 years. Germ banks and some storage systems are known to preserve viability and proximate characteristics of stored materials for decades.

2.2 Classification Based on scale of Storage

Storage systems are classified in terms of size or scale of storage as:

- Small Scale Storage
- Medium Scale Storage
- Large Scale Storage

Small scale storage systems have capacity for up to 1 ton, but not beyond. They are mostly used at domestic and peasant levels. They are associated with peasant farmers with small farm holdings. Medium scale storage can accommodate up to a hundred tons of stored products. Most of such storage systems are in the capacity range of 2 – 50 tons, with very few having capacity beyond 50 tons. Some are used in breweries for temporary storage of spent grains. Large scale storage can accommodated stored material in 100s and1000s of tons. It is used either for temporary or permanent storage of very large quantity of various products. It has a very high initial cost but eventually reduces overall unit cost of production.

2.3 Classification Based on Principle of Operation of the Storage System

Storage systems can be classified in terms of principle of operation. These include:

- Physical Storage
- Chemical Storage
- Biological Storage

Physical storage utilizes physical principles to achieve storage and preservation the quality of stored products. The physical environment (in terms of moisture content, temperature and relative humidity) within the storage system is mostly controlled or manipulated to retard the activities of agents of deterioration or prevent deterioration. Example include cold storage and controlled environment.

Chemical storage utilizes chemicals to stop or retard the activities of agents of deterioration. The use of chemicals such as wax, atelic, or phosphosene dust or tablet to prevent respiration or insect infestation in stored produce are examples. Some chemicals are however poisonous and their uses must be highly monitored, e.g. phosphosene.

Biological storage utilizes biological agents, especially micro organism, to stop or retard the activities of agents of deterioration or enhance the shelf life of stored products. This is a very good area of the application of bio-technology in agriculture.

STORAGE STRUCTURES

The facilities that house stored materials for the purpose of preserving their qualities are called storage structures. The selection of storage structures depend on the production level, cultural practices, and the climatic conditions. Broadly, storage structures are classified as:

- Traditional Structures: Small sized and short term with high level of infestation. They are mostly made of unrefined local materials
- Modern Structures: Mostly large capacity and long term with better regulation of the storage environment. They are made of improved and refined materials

Traditional Storage Structures

These are devices used mostly for short term and small scale storage. Occasionally they include some medium term and medium scale storage devices. They require low level of scientific knowledge to construct, operate and maintain. They are mostly made of unrefined local materials. More than three-quarters of the agricultural output of African smallholder farmers is kept at village level for local use and stored using traditional methods. Storage at the household level offers several advantages:

-It stores food close to the majority consumer

-It gives farmers easy access to their assets and facilitates sale transactions

-It does away with transport and handling costs and eliminates losses which occur at this level.

-It serves as a source of information regarding the supply of grain on the market which informs production decisions. If the household storage is still full when farming preparations are underway, this might signal that there is still an oversupply of the type of grain on the market. An informed farmer may reduce his acreage from the over supplied grain to another crop.

The type of foodstuff and the size of the crop to be stored determine the design and capacity of these facilities. Farmers store their crops either outside, suspended or on platforms, or in granaries, or even inside their homes.

Traditional storage structures include:

- Aerial storage
- Storage on the ground
- Domestic structures
- Rhombus
- Traditional Crib
- Barn
- Shelf
- Pit/ Underground Storage, etc.

Aerial storage

Unshelled maize cobs and other unthreshed cereals are suspended in bunches or sheaves, using rope or plant material, under eaves, from the branches of trees or the top poles driven into the ground. The grain dries in the air and the sun until it is needed by the farmer for consumption or marketing. The disadvantage is that the grain is exposed to the environment and pests.

Storage on the ground

This is for temporary storage, following on immediately from harvesting and lasting only a few days, either because the farmer had not had time to bring in what he has harvested or because he wants to let it dry in this manner for a while when there is no prospect of rain. Storage on the ground is not efficient and not good in tropical areas because of the high incidence of damp. If a farmer uses this method the grain should be placed on a tarpaulin

Platforms

The practice of gathering harvested crops at strategic locations on the field while the harvesting operation is in progress and for such gatherings to be conveyed eventually to the central farm store either at the end of the daily or entire harvest operation is a common practice with peasant agriculture. To further reduce the moisture content of the harvested produce for effective storage, the small produce pilings scattered all over the field were often left in place for weeks before being collected to the central farm store. While this method partially helped in reducing the moisture content of the produce especially those at the top layer, it was found that the bottom layer increased in moisture content due to rising ground moisture. The produce was also attacked by termites and other insects while rodents had easy access to it. Because the field was even bushy, some of such gatherings were forgotten. A platform consists essentially of a number of relatively straight poles laid horizontally on a series of upright posts. If the platform is constructed inside a building, it may be raised just 35 - 40 cm above ground level to facilitate cleaning and inspection. Platforms in the open may be raised at least 1 meter above ground. Platforms are usually rectangular in shape, but circular or polygonal platforms are common in some countries. Grain is stored on platforms in heaps, in woven baskets or in bags. In humid countries fires may be lit under elevated platforms, to dry the produce and deter insects or other pests. Instead of being horizontal and flat, the platform may be conical in shape; conical platforms are pointed at the bottom and are up to 3 meters in diameter. Such platforms facilitate drying because of their funnel shape.

At the top they consist of a frame of horizontal poles which is square, circular or polygonal in shape, against which the timbers which form the cone rest. These timbers meet at the bottom on a wide central supporting post.

Dwellings

Unthreshed cereals are commonly stored under the roof of dwellings, hanging from the roof timbers or spread out on a grid above the fire, the heat and smoke ensuring that the insects are deterred. These grain reserves are intended for day to day consumption because they are within easy reach and safe from theft and pests.

Domestic structures

This is the family level storage practiced in household. Some of the facilities used for domestic storage include guards, tin, box, basket, jute bag, polythene bag, and earthen pot, plastic or metal containers. It is advisable to cover the tin used for domestic storage of grains. The open end of polythene bag should also be tied. This is to ensure air-tight. Oxygen circulation is minimized and this retards the activities of insects. Products stored in domestic structures are preserved with powdered pepper. It is not advisable to store domestic food stuff with chemicals.

They are used at household and peasant levels for the storage of grain. Earthen pots are equally used for storage of fruits such as orange. Though small scale and short term in nature, they are very effective if used under air tight conditions. Items stored in these systems are locally preserved with wood or bone ash or powdered pepper

Rhumbus & Traditional Crib

These are used for grain storage, mostly materials in cob. Rhombus is mostly used in Northern Nigeria while the traditional crib is used in South Western and Eastern Nigeria. Rhombus is cylindrical in shape while crib has rectangular shape. They are made of palm font leaf, clay, tree stem and bamboo. The raised floor could be supported on wooden columns, columns made from mud or stones and the objective is to protect the structure from ground moisture and surface run-off form rain water. Major disadvantages are moisture build as a result of rain, and micro organism infestation. Sometimes coal or wood heat is introduced at the lower base to ensure drying. They are mostly made of local materials such as palm frond, raffia leaf, bamboo, clay, straw and grass. Grains stored in traditional storage structures are not properly protected from rain. Micro-organism infestation is common in the traditional storage. On the basis of material of construction, rhumbu are often grouped into two. The first group is the dried earth rhumbu. These consist of a bin resting on large stones and covered with a thatched roof. The wall of the bin is made either of dried earth or a mixture of earth and grass, or plant stems and covered with mud plaster. They could be covered with thatch to prevent rain erosion. The second type consists of a platform raised on wood or stones which supports a container often covered with a thatched roof. The container is made of

various plant materials such as grass matting and cereal stems, or a mixture of straw and animal dung. The floor could be made of wood or wood plastered with mud. The rhumbu is both an on-farm and village storage structure. It can be used to store grains and legumes such as maize, guinea corn and cowpea. One or more openings are usually provided for loading and unloading. It is mainly used in relatively dry environment and in places where grass and animal dung are available for its construction.

Drying rate is also retarded in the traditional storage. A distinct improvement on platforms, a crib has ventilated sides made of bamboo grass stalks or even wire netting. It should face such a way that the prevailing winds blow perpendicular to the length.

In humid countries where grain cannot be dried adequately prior to storage and needs to be kept well aerated during the storage period, traditional granaries (cribs) are usually constructed entirely out of plant materials. This includes timber, reeds and bamboo which provide good ventilation. Storage cribs made of wood and chicken-wire have been accepted by some farmers while others do not use it because the sides made of chicken wire made the contents visible and were easy to steal from. The crib is basically a rectangular shaped enclosed structure elevated between 0.5m to 1.0m above the natural ground and supported on columns, the purpose of which is to guide against ground moisture, aid ventilation and protect the stored produce from insects and rodents. This protection against rodents is further enhanced by attaching rodents' guards which are inverted funnel-shaped metals on the supporting columns of the crib.

Plate 1: A rhumbu and a traditional crib with maize stored in bags

In bamboo cribs, the supporting columns or poles, the floors and walls are made of bamboo while the wall could be covered with palm leaves occasionally. The roof is thatched with raffia or palm leaves or any other straw material. The supporting poles and floors of the wooden cribs are made from well treated wooden beams and columns. The roof could either be of corrugated iron sheet or wood while the walls are made of wire netting and wooden strips. The metal cribs are the most expensive and durable of all the types of cribs. The poles. Floor and roofing are

made from metals. The roofing cover is corrugated iron sheets while the walls are made of wire mesh and metal strips adequately fastened together. The crib performs double functions as a drier and a storage structure. To effectively perform the drying function, the length side is usually oriented in a direction perpendicular to the direction of the main winds. It is often referred to as the farmers' companion because it enables the farmers to harvest their produce early and at high moisture content thereby releasing the land for second cropping. The crib also enables the farmers to spend their time doing other jobs while the crops dry gradually in the crib to be shelled or threshed later at a more convenient time.

In the design, construction and utilization of a crib, the following factors should be considered;

- The crib must have adequate strength to be self supporting and to hold material both during loading and while in storage.
- It must have adequate strength to resist other external liveloads such as those from wind, snow etc.
- There must be adequate ventilation to ensure effective drying since that is a primary reason for the popularity of the structure among small scale farmers.
- It should be reasonable in cots of acquisition by taking into account the poor economy of most farming communities especially in the developing countries.
- In many occasions the loading and unloading is manually done. Appropriate accessories such as loading steps must be available for ease of these operations.
- While the exposure of the structure and its content to the natural weather condition is desirable, the stored produce must be protected from direct rain and snow.
- The contents of the crib are a food source for rodents and insects. The structure should offer protection against these agents of food spoilage and losses.

The crib was originally used for the storage of maize but at present, the use has been extended to include virtually all other crops.

Barn, Shelf and Pit

The traditional yam barn is basically a framework of vertically arranged wooden poles, each pole measuring between 2 – 4 metres in heights. The poles are arranged at about 50cm apart and may be held together by more rigid horizontal wooden sticks for stability. The spacing between the columns is selected such that when the tubers are put in place, they form a closed wall but with a provision made for entrance. Yam tubers are fastened individually to the poles by means of strings or other local cordage materials such as raffia. The shape of the barn could be circular or rectangular depending on the owner's interest. Shades are always provided for the barn using spear grass, palm fronds and leaves, raffia palm or banana leaves. The materials for the barn construction are usually gottten from the immediate environment and the skill

needed for construction and placement of the tubers is simple. In some situations, the shaded enclosure within the barns provides a good storage environment and yam tubers are placed on the floors. These are mostly used for root and tuber crops. Barn and shelf could be suitable for onion & carrot. Barn, shelf and pit are recommended for cassava, yam and cocoyam. They are affected by environmental conditions.

Pit/ underground structure is the commonest storage recommended for root crops such as cassava and yam tuber. The walls of the pit are lined with nylon or straw. The products are properly packed in the pit and insulated from each other with saw dust. Pit storage conserves the moisture of stored product. It is advisable to store cassava in the pit with its stem. Bruised tubers and cassava must not be stored in pit. Tuber crops are highly perishable. Underground storage is therefore a short-term.

(a) Site Selection – as an underground store, efforts must be made to reduce the amount of moisture from any source that could come in contact with the stored produce. This is often achieved by locating the pits in well drained places and areas where the water table is low such as hill tops and slopes. They perform best in regions of relatively light rainfall. The soil on which the pit is located must be stable to guide against caving-in and land subsidence. The soil should be free of termites, nematodes and other soil residing micro and macro-organisms which attack and destroy the produce in the store.

(b) Construction – The shape of the pit could be circular, rectangular, oval or flask shaped depending on individual interest and the crop to be stored. The shape, dimensions and hence the capacity of the pit are often based on local expertise, rather on rigorous engineering calculations:

(1)The construction involves the excavation and removal of soil from the proposed pit location. The sides of the pit could be vertical or sloped depending on the soil stability and the shape desired.

(2)The walls and floor of the pit are treated with non-toxic chemicals as protection against insects and other soil residing organisms. This treatment is important even if there is no sign of the presence of any insects at the construction stage, the produce to be stored later would provide a good host to which insects would be attracted. The chemical must be thoroughly sprayed all over the floor and walls and in sufficient quantity to ensure adequate penetration into the soil.

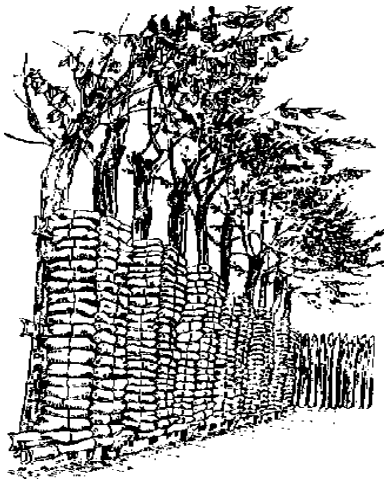
(3)The floor and walls of the pit are then lined with a suitable material which could be straw, mats , plastic sheets and bags, concrete and bitumen, stones, bricks, gravels and wood to prevent the walls from caving in. The use of plastic materials, bitumen and concrete result in moisture-tight pits and excludes ground moisture entry, inhibit the

penetration of micro organism into the produce storred. The use of straw however does not provide moisture tight structure.

(4)The construction of the pit is concluded with a dwarf wall around it to direct away surface runoff and a shed against water.

(c) Methods of use – the method of use depends on the crop to be stored. For grains, the produce is filled in as a single layer or batch, but for tubers, the produce is arranged in layers which are alternated with layers of straw. When the structure has been filled to capacity, a layer of straw is spread over the produce and then covered with earth. The benefits of the underground pits are that the temperature variation is very low, the low level of oxygen restricts insects infestation, the technology of construction is simple, it is cheap as the skill required for construction and management is often available in the locality and there is no risk of pilferage or fire. Among the demerits is the possibility of stored products being infested with pests such as rats and rodents which bore their holes through the soil

Shelf is an improved storage for root crops. Root crops could be stored on shelf for a longer time, though moisture loss is much. Shelf is mostly made of wood or metal. Individual shelf has up to 5 rows. The rows must not be overloaded and proper air circulation must be ensured. Shelf could also be adapted for the storage of onion.



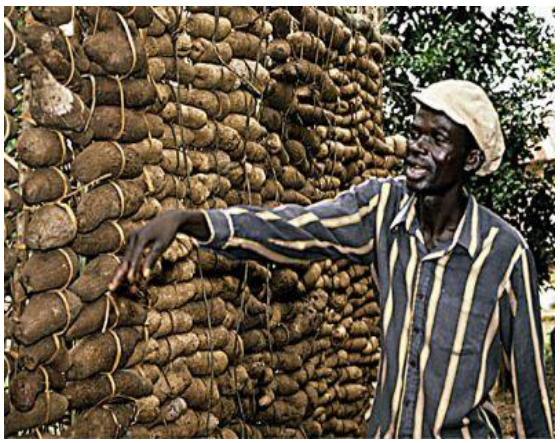


Plate 2: Yam barns

Plate 3: Yam Shelf

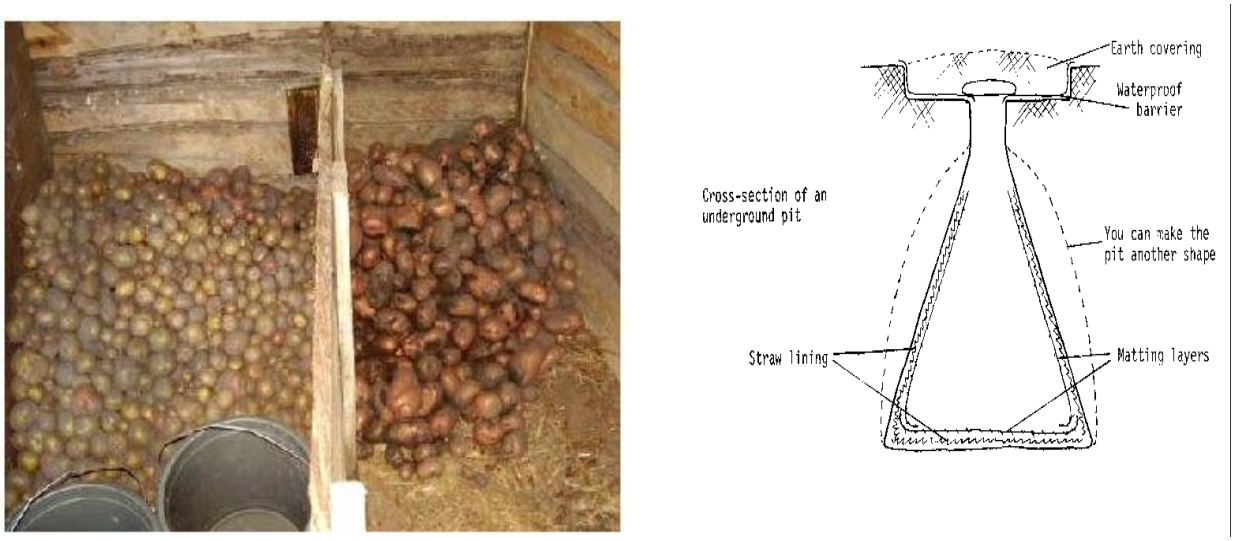


Plate 4: Pit Storage

Modern Storage Structures

Modern storage structures are mostly used for medium or long term and medium or large scale storage.

These include:

- Improved crib
- Ware house
- Silo/ Bin
- Controlled atmosphere storage system
- Refrigeration
- Cold storage
- Evaporative coolant system (ECS)
- Hermetic and nitrogen storage systems

Improved Crib

Improved crib storage has recently grained research interest because of its potentials. The traditional crib storage has been improved. We have the conventional crib storage made of improved material such as sawn wood, iron, wire mesh, galvanized sheet, plastic roof and treated bamboo. The conventional crib has adequate aeration, retarded mould growth and

insect infestation and the roof considerably protects stored crop from direct rainfall. Conventional cribs have increased capacity and could store up to 15 tons of cob maize. It is therefore, used for medium scale storage. The long side of the crib should face the windward direction for proper aeration. However, the performance of the conventional crib is not optimal during the raining season. This is because it is exposed and the performance is affected by the climatic conditions. Improved crib structure is an improvement over the traditional crib in terms of design, capacity, construction material and performance. It has upgraded the traditional crib to medium scale storage. Each unit can accommodate 10-20 tons. An improvement over the conventional crib storage is the 'In-bin' crib. The storage chamber of the In-bin crib is not directly exposed. It is enclosed in a metal bin. This crib utilizes a suction fan to ensure adequate air circulation. This crib is known to prevent product from being contaminated with dust and particulate material. Moisture build is also reduced during the raining season. This crib is however still experimental. However, it has not being commercialized.

Warehouse

Ware house is used for medium but mostly large scale storage for bagged or pilled/ bulk products such as grains, flour, etc. Wooden pallets are used for staking. Material handling and ventilation equipments are essential. Prevention of roof leakage and water infiltration through the floor are most essential. Water proof materials are used for flooring & proper drainage important.

Bagged products are normally stored in the warehouse. Occasionally, bulk materials are also stored in the warehouse. Modern warehouse are provided with material handling equipment especially when bulk materials are stored. Leaking roofs and cracked walls must not be allowed in warehouse. Bagged product are properly stacked on wooden platforms. Effective spacing requirement for warehouse storage is $1.7m^3$ for one ton of grains. However, some allowances should be provided for stacks (platforms) and ventilation. Some warehouses are provided with aerators. The floor of warehouse must be well above the ground level to prevent flooding and a solid foundation must be provided. Water proof materials could be constituents of the foundation. This is to prevent water seepage. The floor should be provided with a proper drainage.

Plate 5: Modern Warehouse

Where farmers come together in formal groups they often consider establishing communal stores that are managed by a trained store manager. The individual farmers can consolidate their stocks ready for the market by delivering to the communal store. This arrangement may be the better option for small holder farmers who do not have the capital to put up own stores, have limitations of land available for the store or do not know how to store commodity well for extended periods of time. These stores work extremely well as bulking centers where large traders come and pickup truck loads of commodity (preferably of the same quality) at one time. The advantage to the big buyer is the reduction in the cost of buying through multiple aggregate traders with their multiplied handling costs.

Some of the basic factors to taken into consideration in warehouse design and construction includes:

- The site where the building is located must be well drained and not subjected to flooding. A swampy location will not only encourage the penetration of ground moisture into the stored produce but the soil bearing capacity would be reduced as the moisture content increases and there is a tendency towards failure.
- The floor in addition should be made moisture proof by incorporating a moisture barrier in the foundation layer before putting the final concrete.
- The wall should be plastered smooth and devoid of any crack where insects may hibernate or hide.
- The doors and windows should be tight fitting to provide partially air-tight condition for fumigation purposes which may be required from time to time. Such tight fitting condition will also help to control the entry of rodents.
- The roof should b leak proof to prevent the entry of rain water into the store.

- The eaves should be completely sealed such that they do not provide avenue for entry by birds and rodents.

Space Requirement of a warehouse : Usually a warehouse is used to store grains in bags and stacked on pallets. The space requirement in a warehouse can be established using the following procedures:

- Determine the number of bags using the relationship between the total amount of grains to be stored and the weight of one bag.
- Decide on the number of bags per pallet, and this will give the total number of pallets.
- Determine the dimension of a pallet which will depend on the dimension of the bag.
- Decide on the arrangement of the pallets and the spacing between them, the spacings between the walls and those pallets nearest to the walls in both the length and width directions.
- The height of the pile or stack will determine the height of the wall after makng provision for head space to aid ventilation.

Silo/ Bin

Silo is a cylindrically shaped structure used for bulk storage of shelled grains in large scale and for long term. Moisture migration and condensation are major problems of silo. Hence, the need for accessories such as material handling and drying equipments. Design, operation and maintenance of silo require high level of skill & technicalities.

Silo is used for bulk grain storage. It is used as a large scale and long term storage. Silo is known to effectively store grains in the temperate regions for decades. Most silos are cylindrical in shape and constructed of metal, aluminum, rubber or concrete. Moisture migration and moisture condensation are the major problems militating against the use of silo storage in the tropics. Approaches to solve these problems include the provision of auger agitator and dryer; using of nitrogen atmosphere, airtight, and the introduction of insulations. Material handling equipments are accessories to silo storage. Silo is very costly. Some of them are monitored by computers

Plate 6: Silos

Silos are an efficient method of storing grain; bulk grain takes less space and can be handled mechanically reducing bagging and handling costs. Recycling grain in silos helps through aeration to reduce potential increases in grain There are different types of silos of various sizes for storing grain in bulk. Bolted corrugated steel silo models are becoming popular in most grain producing countries because they are effective and relatively cheap. The disadvantage of bulk facilities is that in the case of underutilization they cannot be used for other activities.

5.2.3.1 Factors Considered in Silo Design

In designing storage bin the following factors must be given careful consideration:

i. System capacity
ii. Location and orientation of bin
iii. Handling method and equipments
iv. Structural requirements

(i) System Capacity: It is necessary to know the tonnage or capacity of the system. It is therefore, required to know the quantity of grain to be stored and the number of bins to be used. The farmer should decide either to have a single bin with a large capacity or have several small bins. In most cases the advantages of using smaller bins override the use of single bin. Grains can be changed from one bin to the other to prevent caking and deterioration. The use of smaller bins provides flexibility and future adaptations.

(ii) Location and Orientation of Bin

This has a major influence on the efficiency of the system. The location will depend on the end use of the stored grains. Location of bin should be done such that excessive handling is minimized. Bins should be installed or constructed on solid foundations. The site must be

accessible even during the rainy periods. There must be adequate supply of power. Storage bin should be sited at about 60m away from residence because of the noise produced by the dryer and handling equipment. Orientation of the bin in relation to wind and storm must be proper. Bin should be located on a well drained land to avoid flooding. Otherwise, the bin should be located on elevated foundation.

(iii) Handling Method & Equipment

Bin storage basically requires material handling equipments especially conveyors. These equipments are used in loading and off-loading. Screw conveyors and belt conveyors are especially required. Bins are usually loaded from the top and off- loaded from the bottom. Handling equipment could either be portable or permanent. However, excessive handling equipments should be eliminated to minimize cost.

(iv) Structural Requirements: Storage bin should be able to withstand the various forces acting on it. Bin could have rectangular or circular cross-section but circular bins are preferable because of the lack of corner effect.

Storage structures are classified either as deep bins or shallow bins. Generally, shallow bin is the one which has a depth less than the least lateral dimension of the bin while a deep bin has a depth greater than the least lateral dimension.

Janssen, 1878, studied the pressures in deep bins and established the following relationship:

$$P = \int_0^h L\,dh \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Fv = \mu' P = \mu' \int_0^h L\,dh \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$L = (wR/\mu')\,(1 - e^{-k\mu' h/R}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Where, for a consistent system of units

L = Lateral pressure

w = Grain specific weight

μ' = Coeff of friction b/w grain and bin wall

R = area of bin floor divided by the perimeter k = ratio of lateral o vertical pressure in grain

h = Depth of grain to point under consideration

Fv = Vertical wall load per unit perimeter

P = Total lateral wall load per unit perimeter

Janssen assumed that k was constant throughout the grain mass in the bin under consideration. Also, for deep bins, the vertical pressure (v) on the floor is determined by the ratio of L & k.

Thus, if L is determined for a maximum depth, h, the floor land, V,

per unit area is given by

$$V = \frac{L}{k} \quad \text{……..……. (4)}$$

Note that $k = \frac{1 - \sin \Theta}{(5)}$ ……..

where Θ is the angle of internal friction. Mostly

$$0.3 \leq k \leq 0.6$$

Rankine developed the relationship for the pressure in shallow bins. Airy also developed similar equation but Rankine's equation is widely accepted.

Rankine's equation for shallow bins:

$$L = whk \quad \text{……..}$$

(6) The terms are as defined in (3)

Airy's equation for shallow bins:

$$L = \frac{wh}{\left[\sqrt{\mu(\mu + \mu')} + \int(1 + \mu^2)\right]_2} \quad \text{…….. (7)}$$

where

μ = coeff of friction of grain on grain

μ‘ = coeff of friction of grains on bin wall

Both Rankine and Airy assume pressure to be caused by a sliding wedge of grain and that no surcharge exists. Rankine's equation further assumes that there is no frictional force between the stored grain and the bin wall.

Silo Classification

There are different types of silo. Silo can be classified on the basis of:

- Aeration method/ system
- Material of construction
- Level of technology sophistication
- Structural stability

Based on the aeration method, silo can be classified as:

- Mechanical ventilated silo
- Controlled atmosphere silo
- Hermetic silo
- Gas (nitrogen, oxygen, etc) silo

Based on the material of construction, silo can be classified as:

- Metal (aluminum, steel, etc) silo
- Concrete silo
- Wooden silo
- Mud silo
- Composite silo

Based on the level of technology, silo can be classified as:

- Conventional silo
- Instrumentalized silo
- Computerized/ automated silo

Based on structural stability, silo can be classified as:

- Deep silo
- Shallow silo

Controlled Atmosphere (CA)

Controlled atmosphere storage system is a general classification that includes all forms of storage structures that have devices for controlling and monitoring the environmental factors (temperature, relative humidity and moisture). Silo, ware house, refrigerator and cold storage could incorporate controlled atmosphere system.

Plate 7: Controlled Atmosphere

Refrigeration

Refrigeration is a typical CA system that can operate below atmospheric temperature. The evaporator unit of a refrigerator could depress temperature a little below zero degrees through the aid of R12 gas. A refrigerator is made up of components such as condenser, evaporator, compressor, throttle pipes, fan, thermostat, etc. It is used for the storage of highly perishable crop and food materials

Cold Storage

Cold storage is a CA system that can further depress temperature below that of the refrigerator with the aid of R22 gas and maintain temperature below freezing point for a long time. It has similar components like the refrigerator but more bulky, expensive and could store for relatively longer time. It is recommended for highly perishable product with a high commercial value. Products such as fish, egg, dairy, vegetable, meat and poultry products are recommended for cold storage. The initial cost of cold storage is much. Cold storage operates at reduced temperature and regulated relative humidity. The basic advantages of cold storage include:

(i) It retards respiration and other metabolic activities.

(ii) It controls ripening and retards a aging softening, texture and colour change.

(iii) It preserves color and texture.

(iv) It retards moisture loss and wilting.

(v) It controls microbial activities and spoilage.

(vi) It retards spoiling and other undesirable growths.

The following points must be noted for effective performance of cold storage.

(i) The product must be in a good condition to be fit for cold storage.

(ii) Product must be stored immediately after harvest. This is to ensure excessive micro-activity is controlled.

(iii) In-compactable products must not be stored together neither should you store products that do not have the same ripening rate together.

(iv) Once a product chills, it should remain at that temperature before use.

The factors that affect the performance of a cold storage include:

(i) Temperature of Storage: Temperature in cold storage must be uniform within the chambers for uniform ripening. Constant temperature must be maintained. Temperature variation must be minimized to prevent spoilage. For temperature sensitive products, permissible temperature variation is $\pm 0.5^{o}C$ while for non- sensitive temperature product, the permissible value is $\pm 1.5^{o}C$.

(i) Pre-cooling: This is the rapid removal of field heat before storage. It is required for temperature sensitive product, especially fruits. Pre-cooling is achieved either by passing fast cold air through product; or hydro cooling with cold water; or by using ice contact

(ii) Relative Humidity: Different product could be stored at different relative humidity. Relative humidity affects the keeping quality of product. At low relative humidity, product wilts. It is essential to know the appropriate relative humidity to store your product.

(iii) Air Circulation and Package Spacing: Packaging should be done in a cold room such that there is a proper air circulation within and around the product. Also a uniform storage conditions must be maintained in the cold room. Other factors such as the respiration rate of product, heat of evolution and the

refrigeration rate affect the performance of a cold storage.

The following information are essential in the use of cold storage:

- Temperature fluctuations affect temperature sensitive crops. Therefore, keep temperature and storage condition steady and constant
- Pre cool fruits to remove field heat before products are transferred into cold store
- Avoid storing incompatible products
- Ensure adequate ventilation within cold store and use appropriate relative humidity

5.2.7 Evaporative Coolant System

Evaporative coolant system (ECS) is a CA storage system. It slightly depresses temperature below and increases the relative humidity above atmospheric conditions by natural means. It is appropriate for the storage of fruits & vegetables. ECS utilizes the principle of evaporation occurring at the surface of a wet material to produce cooling inside. Wetted padded materials are normally used as medium of evaporation

5.2.8 Hermetic and Nitrogen Storage Systems

Hermetic storage structure prevents air absorption into the stored products in order to disallow metabolic activities of any form by the product, micro organism or insect. Consequently, hot spot, wet spot and moisture build in storage systems are prevented.

Gas (nitrogen, oxygen, etc) storage structure provides devices that allows essential gas such as nitrogen or oxygen to be introduced and preserved in the system in order to prevent ripening or/ and metabolic activities. Some silo and cold storage structures are provided with such facilities

DESIGN OF SUITABLE STORAGE SYSTEMS FOR TROPICAL CROPS.

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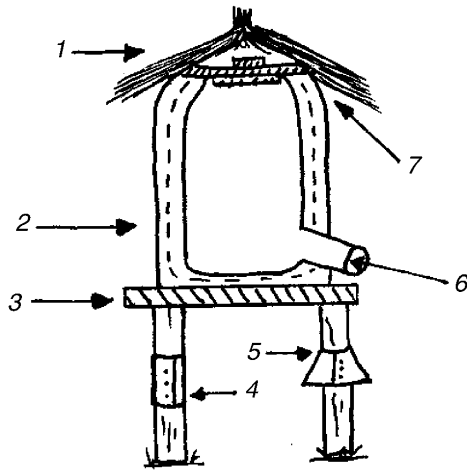

***Figure 1**: Diagram of an improved basket: plastered with clay and raised off the ground on a platform on poles. 1: traditional grass or reed thatch, 2: clay plaster inside & outside, 3: platform, 4 & 5: baffleson poles, 6: tin with press-on lid (e.g. coffee tin) with bottom removed. Set into wall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

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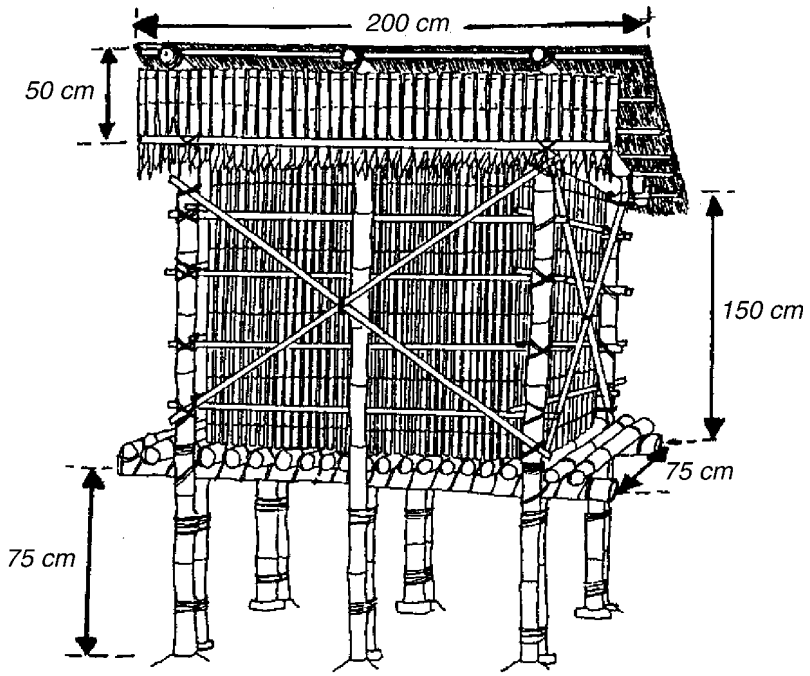

Figure 2: *Maize crib made of bamboo.*

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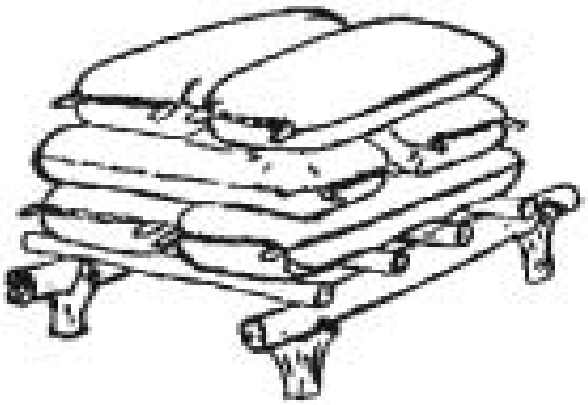

Figure 3: *Pile of sacks on a pallet.*

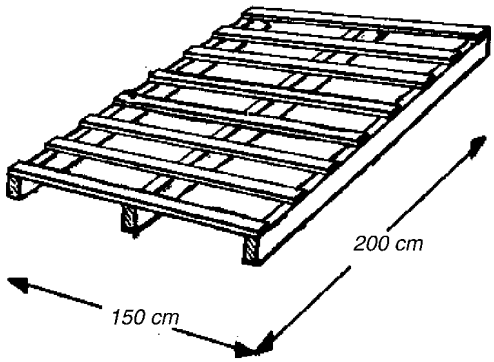

Figure 4: Pallet

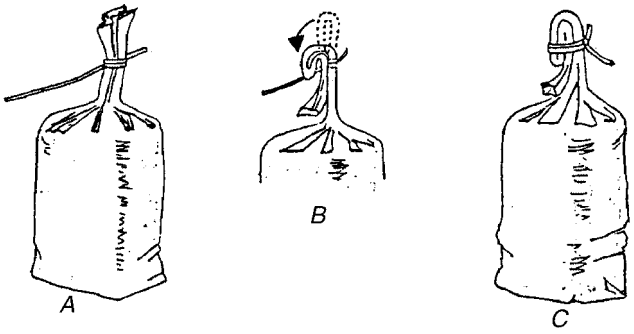

Figure 5: