ABE 523 Food and Crop Storage Engineering

- **Course Content:**
- *Reasons for storage of agricultural products. Review of indigenous and modern systems for storing agricultural and biological materials. Design of storage system and structures for tropical plants and animal products Storage types and environment for Grain and pulses; tubers and bulbs; fruits and vegetables. Storage of perishable agricultural products, control atmosphere and modified atmosphere storage, Storage facilities, distribution criteria, economic analysis of storage systems. Deterioration of produce in storage. Equilibrium moisture content, Sorption isotherms, packaging of agricultural materials. Containerization, Environmental control in storage.*

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Introduction

- What is crops storage?
- Crop storage is the art of holding agricultural crops essentially in their original form under either natural or artificial environmental conditions to retain their quality or quantity over a specific period of time beyond their shelf life without deterioration.
- It is part of the post-harvest system or value chain through which food product passes through on its way from the field to the table.
- Most farm produce begin to undergo deterioration as soon as they are harvested.

- The agents of spoilage include enzymes, environmental conditions, insects and rodents, micro organisms and metabolism.
- The main function of food storage structure is to control the activities of these agents or protect the crop from them
- Storage is an important activity which predates farming. It enhances marketing efficiency by providing time utility.
- Storage is particularly important in agriculture because agricultural production is often seasonal, while the demand is more evenly spread throughout the year.
- Thus there is often the need to provide leverage between supply and demand by storing excess during the harvesting season for gradual release to the market during off season periods.

- Storage is an important aspect of running a farm because;
- Ie ensure steady supply of food throughout the year, since food harvest is seasonal
- guarantee the availability of raw materials to feed the agro allied industries
- keep planting material from generation to the other without loss of viability
- stabilize food prices by stock pilling when food prices are low and releasing into the market when prices go up.
- Encourage farmers to produce more food since the excess of what they produce will not be lost.

- However, crops are stored for different reasons depending on who is storing it. Crop is stored mainly by farmers, traders and governments:
- Farmers store the crops which they grow mainly to meet their house hold food supply during nun production periods. Other reasons farmers store crops is to preserve viability to be planted during the net planting season, to increase profit by selling the crop during the off season when prices are high.
- Traders usually purchase agricultural products during harvesting season and sell it during off season. Their main reason for storage is to make quick profit. Some traders store large quantities of agricultural products to maintain continuous supply of raw materials to the industries.
- Government buy surplus crop from farmers and store it for different reasons. In Nigeria government storage is carried out through the strategic grain reserve storage programme. The reasons for storage of crops by the government are:

- Price stability regulations this is achieve by purchasing crops during harvest period and release in to market during scarcity period.
- For export market this is to enhance export market and boost the economy.
- To assure food security by supplying the citizens with sufficient and quality foods
- Prevention of extinction of original variety, while new variety are developed the original variety is stored to avoid extinction.
- For research purpose, crops are stored in research institutions for purpose of various research.

- For a storage structure to perform its function well, it must be designed to meet the following requirements:
- It should keep product cool and dry
- It should provide protection from insects, birds, mites and rodents
- It should have easy inspection facilities
- It should have facilities for aeration and fumigation
- It should be economical
- It should permit cleaning
- It should protect the produce from fire and theft
- It should have good loading and unloading facilities.

- Important operative factors in crop storage: The condition of crop during storage is affected by a number of factors. These factors should be taken into consideration during designing and construction of the storage structure and while preparing the crop for storage. Operative factors in crop storage are divided into four broad categories. They are: structural factors, physical factors, biological factors and biochemical factors
- Structural factors: the storage structure affect both the quantity and quality of stored crop. The weather, climatic condition, location and cost should be considered in designing and selecting a storage structure.

- Physical factors: the most important of the physical factors are moisture content crop to be stored, relative humidity and temperature of the surrounding and air composition Most agricultural products are hygroscopic, that is they have the tendency to exchange moisture with the storage atmosphere until equilibrium is reached. The moisture content of crops especially grains, oilseeds, etc. is required to be reduced to a minimum level known as 'safe level' before such crop can successfully be stored. Therefore it is important to ensure the safe level of moisture content of the produce and the relative humidity of the atmosphere as well as the way to achieve a balance between both, such that the quality of stored crop is not adversely affected.

- Biological factors: The biological factors involved in crop storage are the most important elements due to the fact that heavy crop losses are caused by these factors while the crop is growing in the field, before and after harvest, during transportation and most significantly during storage. The biological agents of crop deterioration are:

  Insects

  Rodents

  Microorganisms (fungi and bacteria) and

  Birds

- Biochemical factors: These factors affect the nutritive value of crops, the oil content, fatty acids, odours and the flavour. Most of the biochemical factors are affected by the physical and biological factors. The storage system must be such that will maintain the desirable properties of the crop and prevent development of the undesirable ones.

Review of Indigenous and Modern Systems for Storing Agricultural and Biological Materials

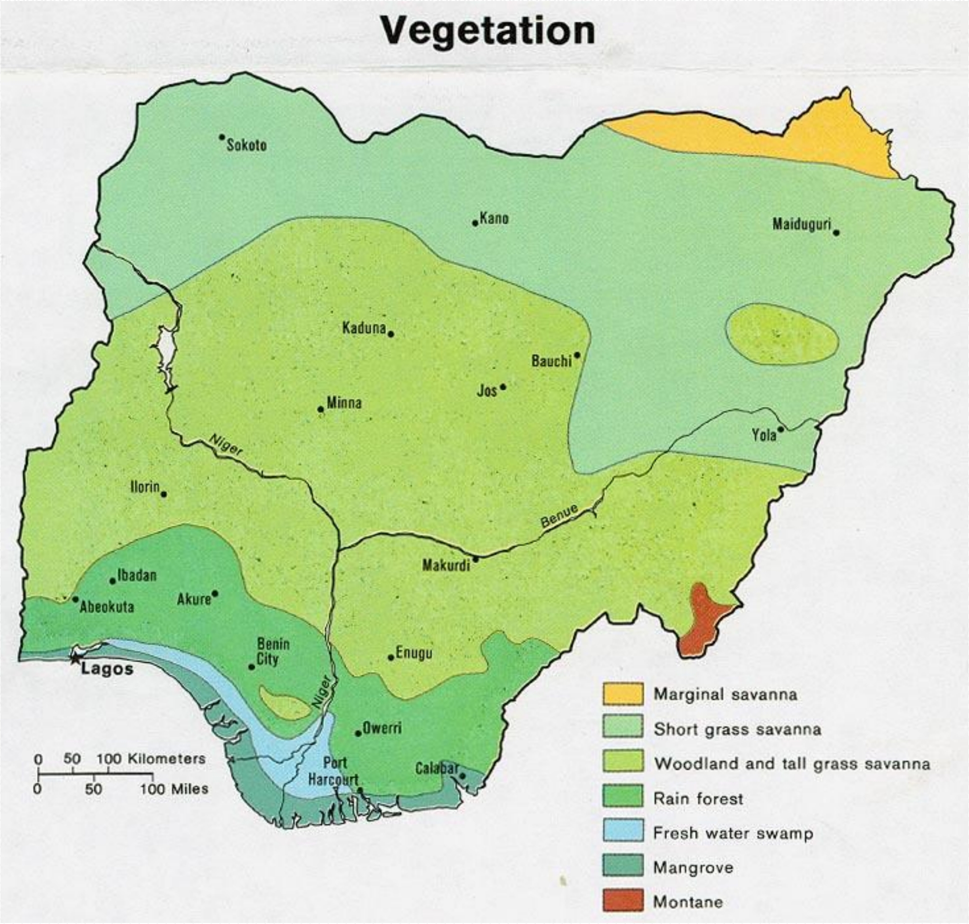
Indigenous storage systems

- Made using locally available materials by local farmers
- Depend on socio-economic & cultural values
- Adapted to climatic conditions

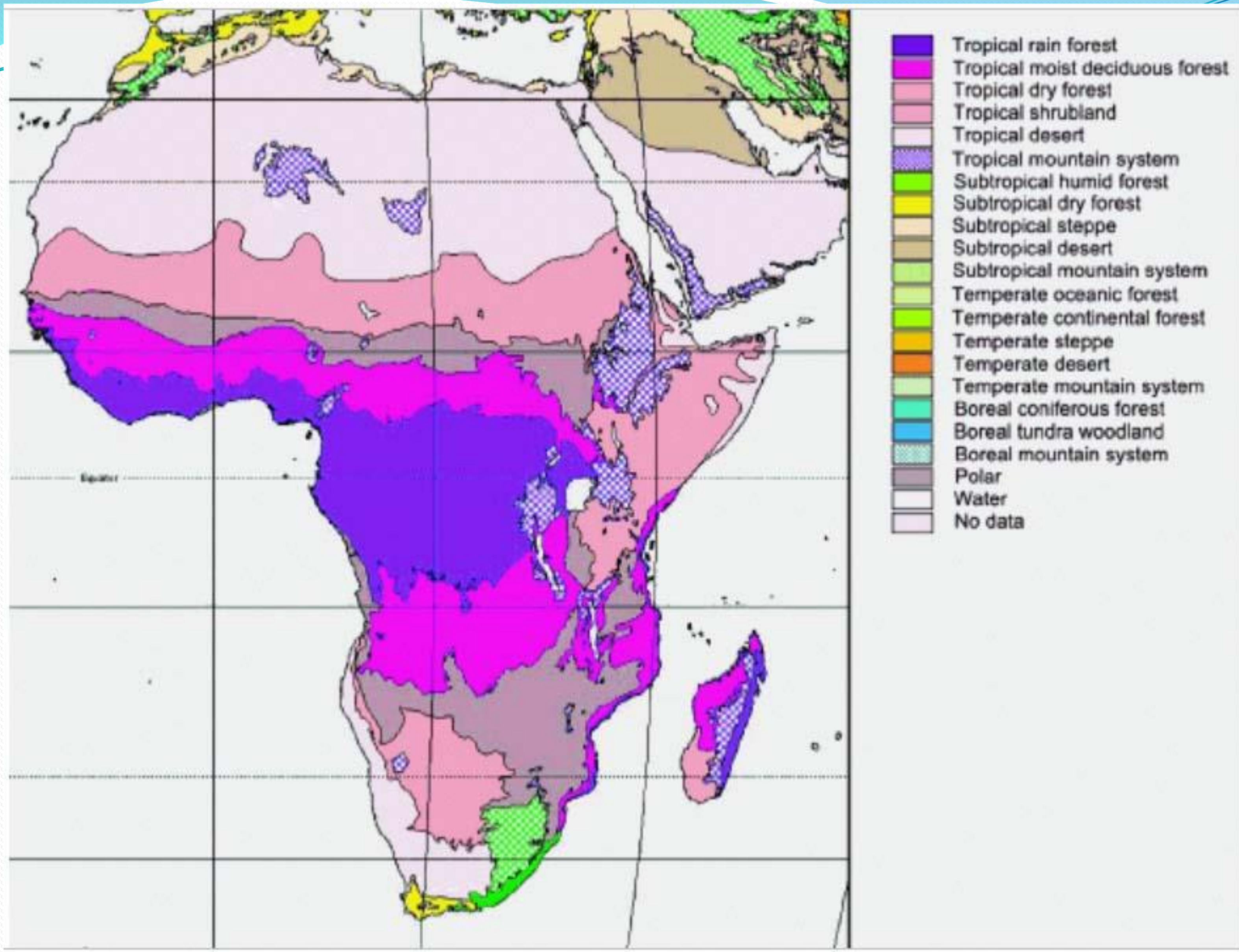
Different structures are used in Nigeria depending the location and crop stored.

For the purpose of classification of indigenous storage structures, Nigeria can be divided into three regions namely,

- The Sudan Savanna covers most of the northern states (Kano, Katsina, Gombe, Adamawa, Sokoto, Kebbi, etc..)
- The Guinea Savanna includes states in the middle belt (Benue, Kogi, FCT, Niger, Nassarawa, Plteau, etc).
- The rain forest zones include those states in the south (Enugu, Anambra, rivers, Edo, Delta, Oyo, Lagos, Ogun etc.).



Vegetation
Sokoto
Kano
Maiduguri
Kaduna
Bauchi
Jos
Minna
Yola
Niger
Ilorin
Benue
Makurdi
Ibadan
Abeokuta
Akure
Benin City
Lagos
Enugu
Niger
Owerri
Port Harcourt
Calabar
0 50 100 Kilometers
0 50 100 Miles
Marginal savanna
Short grass savanna
Woodland and tall grass savanna
Rain forest
Fresh water swamp
Mangrove
Montane



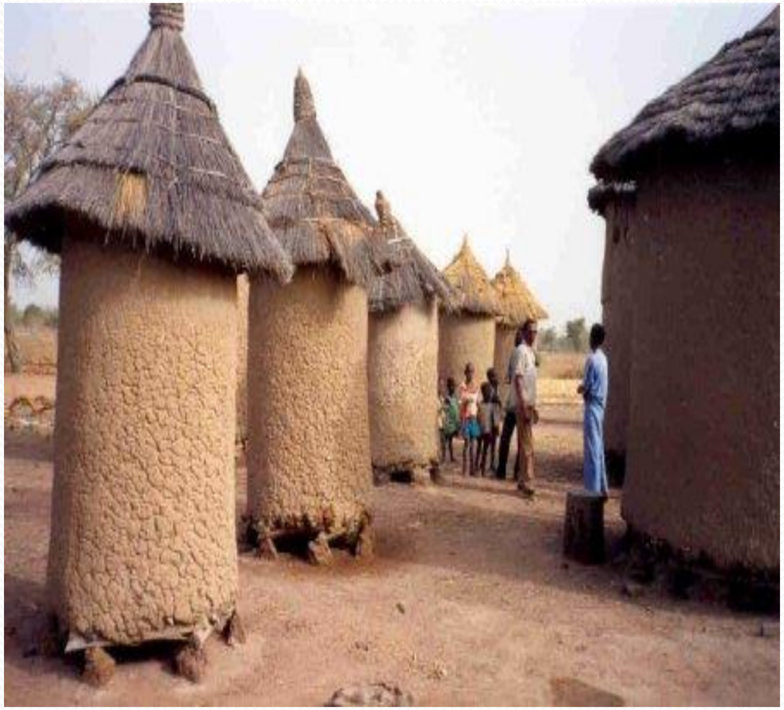
Tropical rain forest
Tropical moist deciduous forest
Tropical dry forest
Tropical shrubland
Tropical desert
Tropical mountain system
Subtropical humid forest
Subtropical dry forest
Subtropical steppe
Subtropical desert
Subtropical mountain system
Temperate oceanic forest
Temperate continental forest
Temperate steppe
Temperate desert
Temperate mountain system
Boreal coniferous forest
Boreal tundra woodland
Boreal mountain system
Polar
Water
No data
Equator

- The Sudan Savanna: Storage structures that can be found in this regions include: the mud rhumbu, thatched rhumbu and underground pit.
- The Guinea Savanna: Storage structures used by farmers in this zone are a bridge between the north and the south. These include mud rhumbu, thatched rhumbu, platform, earthen pot and cribs.
- The rain forest: storage structures in this zone include the crib, platform, barns, indoor containers (jerry cans, earthen pots, plastic & metal containers)

Mud Rhumbu

- Made of mud and thatch or only mud.
- In most cases circular in shape
- supported on stone pieces of 40 to 50 cm above the ground level.
- The floor is constructed with wood and plastered with mud,
- The wall is made of mud putting two to three layers daily.
- In some cases the structure are found completely open at the top and covered with conical thatch roof.
- Or a conical roof of mud is built up during the course of the construction leaving the inlet opening of 50 to 80 cm diameter at the center.
- The wall thickness of the mud rhumbu is 6.5 to 7.5cm
- Capacities range between 3000 to 4000kg. They are used for storage of different commodities of food grain both in threshed and un-threshed conditions,
- Also onions and yam during the rainy season are stored.

Mud Rhumbu



Thatched Rhumbu

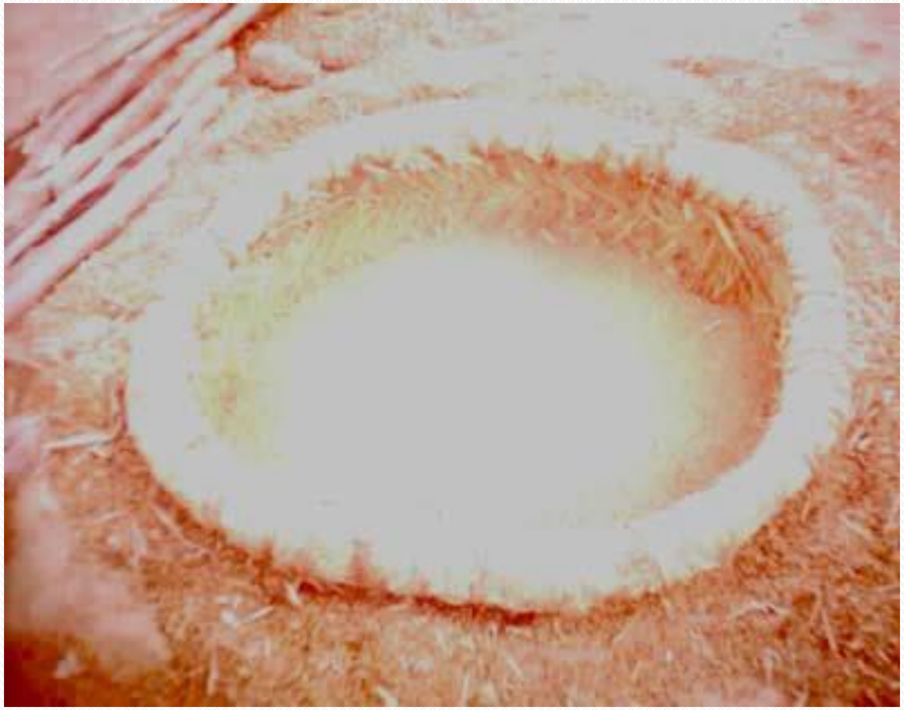
- It is an outdoor structure,
- cylindrical in shape
- with conical thatch roof at the top.
- The structures are placed on low raised wooden platforms and are made of various types of grass.
- Tension rings are provided to give it more strength.
- The capacities range between 1500 to 2000kg.
- They are used to store different grains such as millet and sorghum in un-threshed conditions and groundnut in pods, and onions

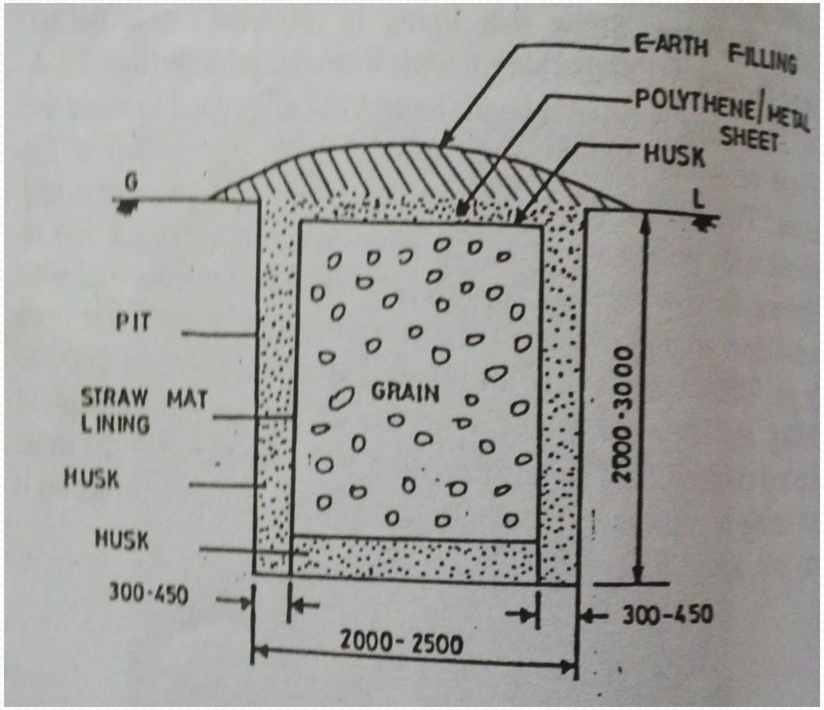
Thatched Rhumbu

Underground Pit Structures

- A circular pit of 2000 to 2500 mm diameter is dug to the depth of 2000 to 3000mm.
- Straw mat lining is provided inside the pit leaving the space 300 to 450mm wide from the pit wall.
- This space is filled up with loos husk all around to avoid seepage of water. a layer of husk is provided at the bottom.
- The entire pit is then filled with threshed grain and covered with polythene sheet a layer of husk and then covered with earth filling, giving a conical shape to drain away the water.
- The capacities of the structures range between 2000 to 3000kg, and they are used for storage of millets and sorghum in threshed conditions.
- The pit may last for 5 – 7 years, but the straw mat lining is replaced after every use.

Pit Structures

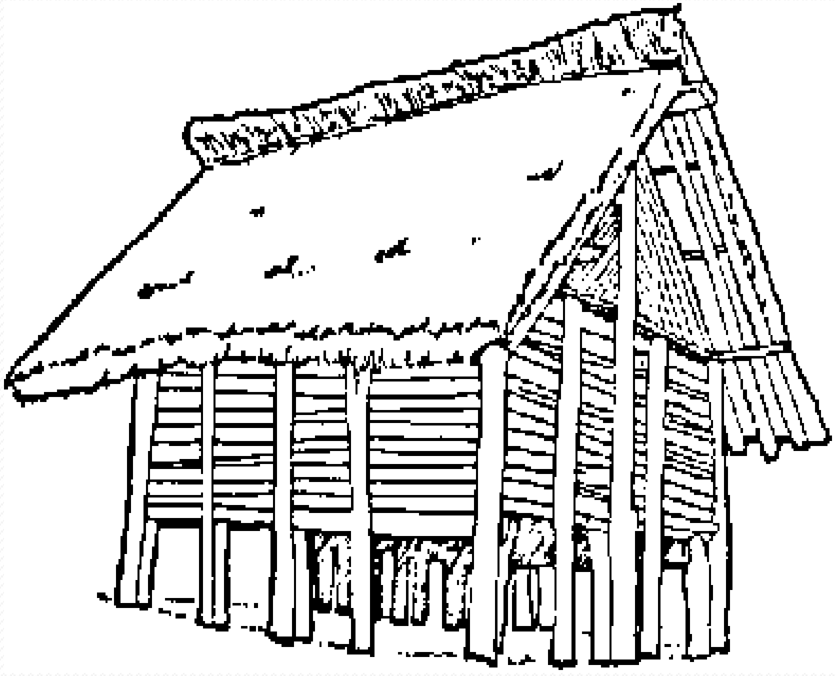




The Crib

- the crib is used to store crops in husked (in bags or baskets) and un-husked form.
- It is an outdoor, rectangular open structure
- It has elevated base 800 – 1000mm made of wood or bamboo and with thatched roof.
- the sides of the structure are made of bamboo, palm fronds, planks or wire netting.
- The cribs capacity is in the range of 1 to 5 tonnes depending on the farmers need
- Its lifespan is 5 to 10 years.

The Crib



Platforms

- These are structures made from straight horizontal poles (wooden or bamboo) laid on vertical ones.
- They are raised at least 1 meter above the ground level and are conventionally rectangular in shape, but can also be circular or polygonal.
- Grains are stored on platforms either in threshed form (in bags or baskets) or un-threshed form.
- Platforms are used as temporary storage structures to gather crops during harvest for later transfer to store or to allow reduction of moisture after harvest for effective storage.
- Platforms can be in door or out door, platforms on fire or platforms under shade.

Platforms

Indoor Containers

- These are used in dry tropical regions as household and farm, village levels for storage of grains in small quantities.
- They are improvised structures
- They form effective long term storage when used under air tight conditions.

Problems of Traditional storage structures :

- Low elevation therefore provide easy access to rats and rodents in to the structure.
- The base is made of wood and is easily damaged by rats and termites.
- They are not moisture proof.
- Because of the week base there is a danger of collapse.
- Not air tight, therefore it is difficult to control insect and pests
- They have poor loading and unloading facilities
- There are chances of grain loss due to fire and theft
- High grain loss due to rats, insects, moisture and termites
- Quality of grain cannot be maintained for a long time
- There is no provision for inspection
- Storage losses are considerably high 40 – 50%
- The life span of the structures is short and annual maintenance cost is high

Modern Storage Methods and Structures.

- Modern storage structures are an improvement on the traditional methods.
- The structures are constructed with the use of modern technologies and have the following advantages:

- They are rat and moisture proof there is no damage due to termites
- They are adequately airtight
- They have efficient method of loading and off loading
- The grains can be stored in threshed condition rather than un-threshed and thereby increase the storage capacity
- There is adequate protection against fire and theft
- The storage losses are comparatively less
- The lifespan of these storage structures are long and annual maintenance cost is low
- Although the initial cost of construction is high annual cost of storage is comparatively less

- Modern storage methods and structures commonly found are the
  - use of silos,
  - ventilated cribs and
  - warehouses.
- Their use and efficiencies vary
  - from place to place
  - according to the climate and
  - management skills.

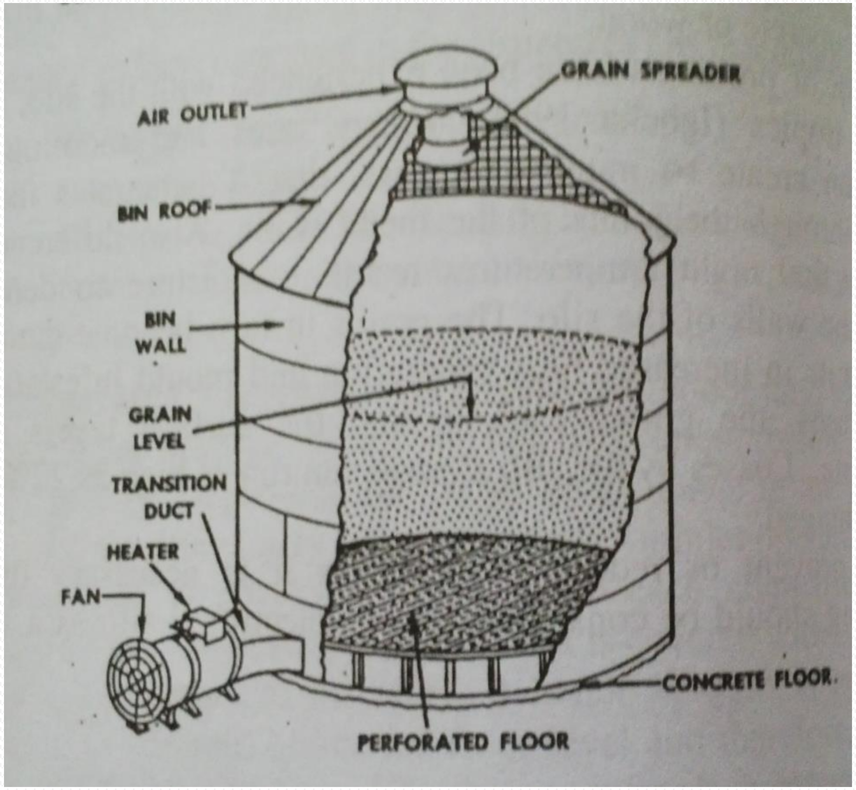
Silo

- used mainly for shelled grain by large scale farmers, processors and government organizations.
- Silo storage involves extra handling operations like shelling, cleaning, conveying and drying.
- It can be made of metal concrete and wood.
- two main types of silos, these are
- The tower silo is a tall cylindrical structure which can be made of concrete or metal. Usual loading and unloading of these silo is by the use of conveyors. In some cases silos are used as dryers, in which case they are equipped with blowers and heaters. There are usually more than one silo in particular installation and they are linked by conveyors.
- Horizontal silos can be above or below ground.
- Underground silos are usually used for silage. The inside of the silo is made of concrete or brick. The material is loaded and covered with straw, which is covered with earth.

Based on aeration methods

- unventilated silos, which is without any ventilation systems;
- ventilated silos which are fitted with fans that push air through the grains
- control atmosphere silos where the atmosphere inside is control (reduced oxygen and high nitrogen or carbon dioxide) and
- hermetic silos which operates by elimination of oxygen in the container to deactivate insect and pest.

Silo

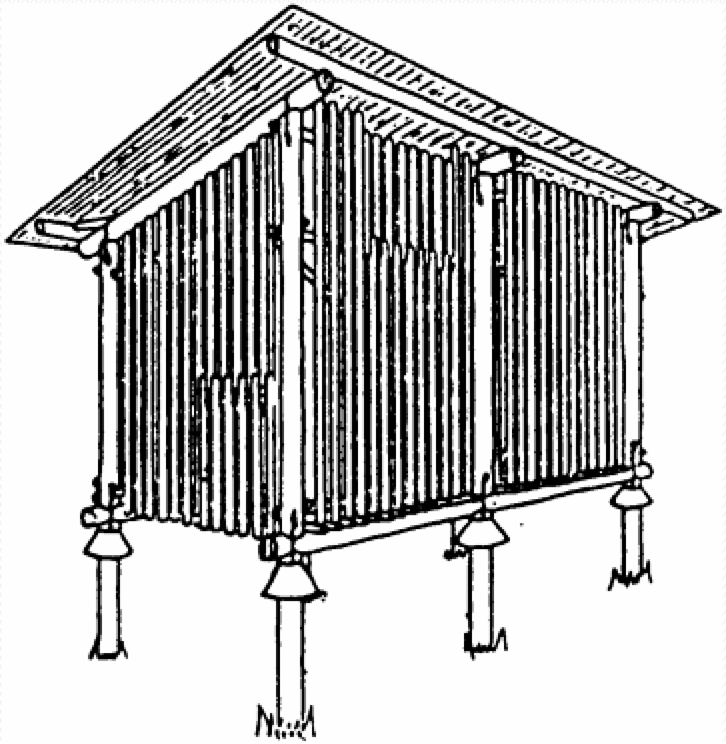


GRAIN SPREADER
AIR OUTLET
BIN ROOF
BIN
WALL
GRAIN
LEVEL
TRANSITION
DUCT
HEATER
FAN
CONCRETE FLOOR
PERFORATED FLOOR

Ventilated crib

- This is an adapted and improved version of the traditional crib storage system.
- The crop to be stored is harvested at high moisture content and dry in storage to moisture content of about 15% within 3 to 4 months of storage.
- The crib consists of a rectangular structure raised from the ground with sides made of wire netting and reinforced with wood.
- It is usually located in a well ventilated area to facilitate aeration and drying of the product.
- Rodents are prevented by installing rodent guards on the legs. Storage losses are relatively low in ventilated crib storage.

Ventilated crib

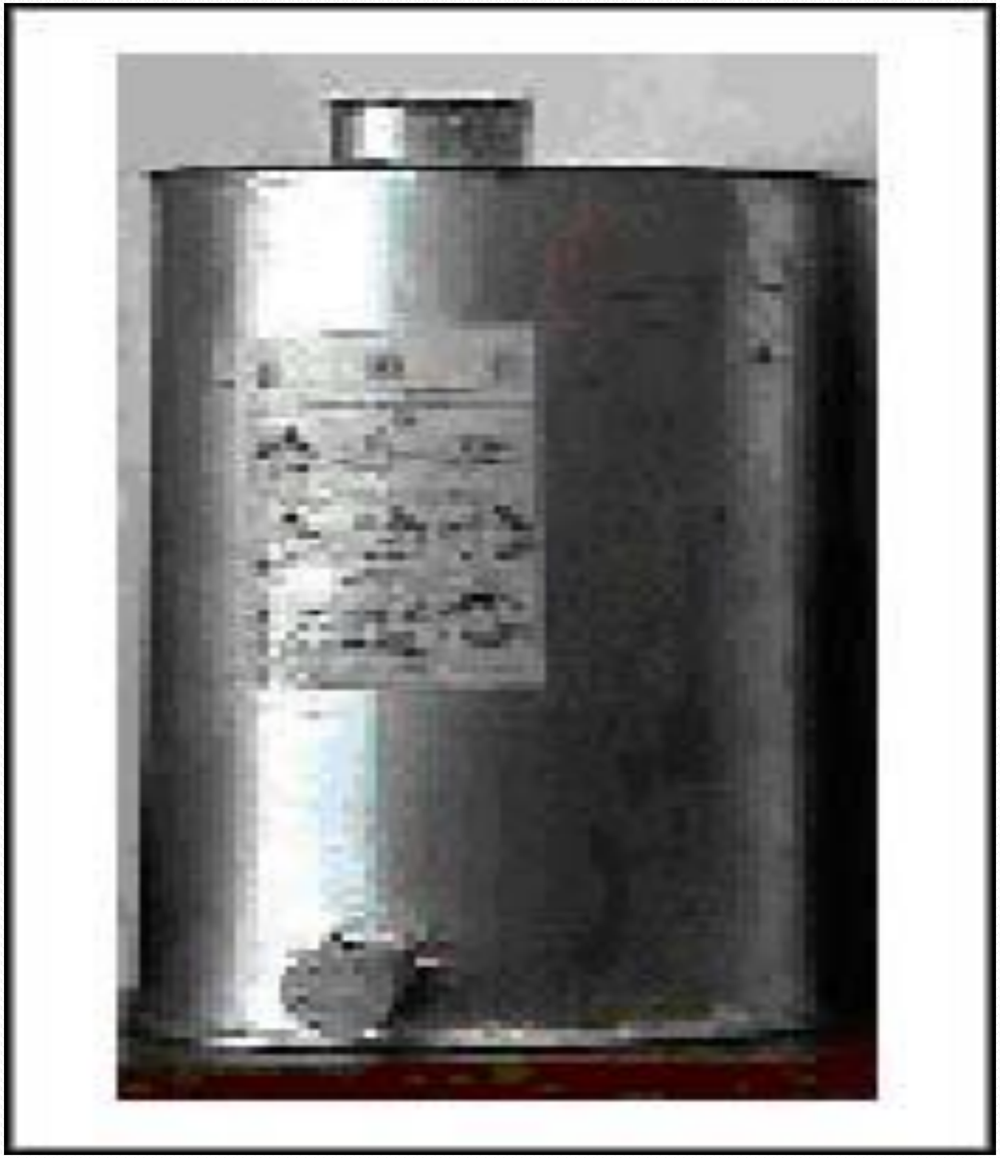


Warehouse storage

- warehouse (bag) storage is the most popular method of storage for medium and large scale farmers.
- They can be used both as temporary and permanent storage structure.
- Losses can be minimum if the ware house is well designed and constructed and storage of the bagged products was done appropriately.

Warehouse storage

Household Metal Silos



Advantages and Benefits of Metal Silos

- it maintains the quality of stored product;
- it is airtight and permits effective non-residual fumigation;
- it avoids the use of insecticides;
- it requires little space and can be placed near the home;
- it reduces losses to virtually nil;
- it enables farmers to take advantage of fluctuating grain prices;
- prevents rodents and other pests that can harm consumer health;
- it is easy to use, profitable and an effective tool against poverty;
- it is inexpensive and can last for more than 15 years, if properly maintained;
- it can hold from 100 to 3 000 kg;
- it facilitates women's work;
- it can be built in situ with local labour and easily available materials;
- it is a form of decentralized storage;
- it is a tried-and-tested technology in several countries.

Planning and Design of storage system and structures

some functional and operational factors that must taken in to considerations when planning and designing modern storage structures include:

- Type of grain and quantity to be stored
- Type and capacity of the structure
- Location (site and orientation)
- Handling methods and equipments
- Structural stability and other requirement
- Constructional materials

Type of crop and quantity to be stored:

- Type of crop and quantity is important in determining storage type, size and the number of units.
- Different types of grain to be stored often dictate the number of storage units to be planned and designed
- It is also important to consider the production capacity, harvesting time and harvesting rate as well as handling techniques required.

Type and capacity of the structure:

- selecting the type of storage structure depends on availability and knowledge.
- Generally in crop storage two storage types are common. This is the bulk and bag storage.
- In selecting type of storage structure and methods consideration should be given to the extra handling operations required like cleaning, conveying, bagging and drying.
- Different agricultural products have different densities and settles at different angles in a bulk pile. The angle of repose also changes with the moisture content and purity of the product in storage. The knowledge of this physical properties help in determining the capacity and size of storage space required.

Location (site and orientation)

- this is important to the systems efficiency and stability. The basic considerations include:
- Proximity: To reduce excessive handling, storage structures should be located close to the point of use such as processing, shelling, threshing, or drying point. Excessive handling usually increases the cost of equipment and labour requirement.
- Site soil characteristics: Storage structures are meant to carry weight. The weight of the structure and the product it carries are borne by the soil. Therefore, it is important that the characteristics of the soil such as load bearing capacity, resistance to compaction and drainage characteristics be determined. Storage structures should be sited on a well drained and level ground, the soil should be hard firm. Underground storage structures should be sited on areas with low water table.

- Accessibility: for easy access and movement of grains, structures should be sited close to well graded major roads. The site must permit easy movement of vehicles around the structure; there should be space for utility structures and future expansion.
- Power supply: Storage structures that require control ventilation, fans for drying and aeration, automatic handling equipment such as conveyors and elevators require that they be sited near adequate source of power.
- Safety: storage structures need to be fumigated from time to time, thus, for safety reasons it should be sited away (at least 60 m) from dwelling of homes and working areas.
- Orientation of the structure: storage structures that require being naturally ventilated such as cribs, and platforms needs to be oriented such that it is not against the wind direction. Longest side should be sited perpendicular to the direction of wind.

Structural Stability requirement:

- ***the primary purpose of*** storage structures is to maintain quality of the stored product. In addition to this storage structures should:
- Withstand the load imposed on it by the crop during storage as well as loading and unloading
- Resist snow and wind loads either when full or empty
- Have properly designed foundation so as to resist uplift

Basic structural requirement for stability in storage structures are:

- Roof: roof should be sealed to prevent penetration of rain; should be designed to shed water quickly without leaking; should keep out rodents, birds, insects etc. should have roof overhang at least 1 m to shed rain water and protect walls from rains and direct sun.
- Floors: floors should be above ground level to allow drainage; should be crack free and reinforced with concrete and should have vapour proof barriers underneath and on top.

- Walls: inside walls should be plastered to allow proper cleaning and pest control and outside wall should be plastered with cement, lime and mortar to keep walls cool and easy to clean. In mechanically ventilated structures, the air inlet and outlet must be adequate to avert excessive static pressure and should be well sealed to prevent entry of rain and adequately screened to prevent entrance of rodent and birds. Walls should have doors wide enough to allow loading and unloading
- Door: all doors should be secured and rodent proof, large enough to allow loading and un loading as well as properly positioned for supplementary ventilation.

Construction material

- Selection of materials for the construction of crop storage is underlined by:
- The nature of the crop
- Duration and use of structure (permanent or temporary)
- Environmental conditions
- Availability and cost of material
- Durability and strength of the material
- Construction materials commonly used for storage structures are:

1. Steel (metal): steel is the most common construction material for modern crop storage structures.

- It is used for silos, metal cribs, drums, and partly for warehouse.
- It is adaptable to high volume, easy to fabricate, has relatively high weight which help in stability,
- it is impervious to moisture penetration thus require no special sealing and has high strength.
- However it corrodes easily except if galvanized to minimize oxidation and moisture effect, it has low resistance to heat, hence require good insulation for crop safety.

- Wood: the use of wood is limited to traditional farm storage structures and a few modern structures such as cribs and warehouse (for roof trusses and doors).
- It has low thermal conductivity and thermal expansivity as well as ease of working.
- However it is easily damaged by high moisture and termite.
- It has to be treated or coated to prevent deterioration.

- **Concrete:** concrete is essentially used in silos and sometimes in under ground silos and pits.
- It is easily adaptable to high volume, has relatively high weight, it has low thermal conductivity and expansivity.
- However, it is characterise by difficulty in moisture proofing and installation of aeration equipment.
- **Plastics:** Plastics have limited use in modern storage because they are susceptible to puncture and breakdown when exposed to sun for a long period.
- They are used mainly as water proofing film under concrete floor linings which prevent moisture from entering the crops through the floor.
- They are also used in form of jars for air tight storage. Polyethylene is used in form of bags for packaging and storing shelled grains.

Quantity of crop to be stored and capacity of the storage structure

- A farmer has 10 ha of land which he planted maize. He is expecting a yield of 4 tonnes/ha at moisture content of 34% wb. The storage moisture content for maize is 14 %wb. Calculate the amount of maize to be stored if the farmer plan to store 70% of his harvest. Also calculate the volume of storage space required if the bulk density of maize is 720 kg/m3

- Total harvest
- 4000 x 10 = 40,000kg
- Amount to be stored
- 40000 x 0.7 = 28,000 kg (at 34 % mc)
- 28,000 ((100 - 34)/(100 – 14)) = 21,488.4 kg (@ 14 %)
- Volume of storage space
- 21,488.4/720 = 29.845 m3

Design Consideration of Silo

- Silos are considered as bins
- Two types of silos are considered

1. Shallow silo (has depth less than the least lateral dimension)
2. Deep silo (has depth greater than the least lateral dimension)

Storage bins should be designed to

- To withstand loads imposed by the grain during storage (static load)
- To withstand loads imposed during movement of grain (dynamic load or overpressure)
- withstand wind loads whether loaded or empty (this should be determined for the site of construction or installation

The major aspect of structural design of silos is

- the prediction with reasonable accuracy the static loads
- the prediction with reasonable accuracy the dynamic loads or overpressure
- The structure is required to withstand these pressure for its service life span
- Two approach to determine total pressure

1. Determine static pressure and modify using overpressure factors
2. Compute total pressure directly

Determining Static Lateral Pressure

- For fine granular materials with average particle diameter less than 2.5 mm

$$P = \frac{2.06\, sin^2 \emptyset \gamma_i^{1.03} D}{\mu^{1.08}} \left(1 - e^{\frac{-2Y\mu}{D}}\right)$$

- For fine granular materials with average particle diameter more than 2.5 mm

$$P = \frac{0.746\sqrt{\sin \emptyset}\ \gamma_i^{1.12} D^{0.91}}{\mu^{0.91}} \left(1 - e^{\frac{2Y\mu}{D}}\right)$$

Where:

- P is average pressure
- Φ is angle of internal friction of the material
- γ_i is unit weight of the material
- μ is silo – crop coefficient of friction
- D is silo dimension
- Y is depth at which pressure is measured

Storage types and environment for Grain and Legumes

- The basic requirements of crop storage system is the elimination, inactivation or effective control of spoilage agents.
- This can be done by the manipulation of the environment in and around the stored products, so as to impose as many unfavourable conditions as necessary to prevent the activities of the spoilage agents.

- In a stored grain bulk there is an interaction among the physical, chemical and biological variables
- These variables can be living organism (biotic factors) and non living environmental (abiotic) factors
- The extent of deterioration during storage will depend on how these variables are managed or manipulated by the storage engineer.
- The biotic variables in stored grains are:
  - the bulk grain which has several physical and biological attributes,
  - micro organism such as fungi and bacteria,
  - anthropods such as insects and mites and vertebrates such as rodents and birds.

- The abiotic environment of the grain includes
  - physical variables such as temperature and relative humidity,
  - chemical variables such as CO_2 and O_2 and
  - biological variables such as respiration.

- Physical factors:

- The main physical properties whose interplay influences the quality of the grain are the flow properties and tendency to natural segregation, porosity, sorption, moisture content, temperature and relative humidity.
- The flow property of grain bulk is affected and determined by the grain angle of repose and the coefficient of friction. These properties are in turn affected by moisture content, cultivar and type of the grain.

- Porosity depends on the size and shape of the grain, weight, level of compaction and distribution of moisture content in the bulk. Porosity and flow properties influence the movement of air, heat and moisture in stored grain.
- Sorption is property inherent in all grains in bulk being hygroscopic in nature. Sorption phenomenon includes adsorption and desorption. Grains sorb moisture or release it to the ambient air until equilibrium is achieved. The sorbed water which has a lower vapour pressure behaves differently from free water. In planning safe storage of grain information on the relationship between moisture content and relative humidity for the particular cereal is very important.

- Temperature of the atmosphere, the grain and inter-granular air are very crucial variables for the safety and prolongation of grain in storage. Heat from the external source penetrate slowly into the grain and affect the temperature around the surface. Other sources of heat are metabolism of dry or damp grain, heat produced by fungi, insects and other organism. Therefore it is very important to monitor continuously the temperature profile of stored grain.

- Relative humidity refer to the amount of water in the air. It is the ratio of water vapour pressure of a sample air to the saturation vapour pressure at the same temperature expressed in percentage. High humid store encourage multiplication of moulds, fungi, insect and pests hence deteriorates grains quality.

- Moisture content of the grain plays a very important part in limiting the development of bacteria, fungi, insects, mites and yeast which are the main reason for spoilage of stored grain. Moisture content below 14% will inhibit the growth of most microorganism and mites. The distribution of moisture within a bulk or silo is not uniform. The moisture distribution pattern depend on the season and the climatic factor. It is therefore important to monitor the moisture content of stored grain.

there is interaction between the factors stated above. The most important interaction in storage is the interaction between temperature, moisture content and relative humidity

- Interaction of temperature and moisture content: a rise in temperature at high grain moisture content will cause grains to loose moisture to air, hence increasing the relative humidity of the store, while a drop in temperature will result in to condensation of moisture in the air on stored grains. Re absorption of condensation causes change in texture, colour, flavour and nutritive value. Ventilation and regular monitoring of temperature and moisture content is essential in stored grains.

- Interaction of temperature and relative humidity: Change in temperature of grains stored cause a corresponding change in relative humidity, reduction in temperature will cause condensation. For effective grain storage it is important both temperature and relative humidity be kept low by regular ventilation.
- Interaction of moisture content and relative humidity: The level of relative humidity and moisture content directly influence the susceptibility of grains to deterioration. Under high relative humidity the air within the store can deposit moisture on stored grain if the grain moisture content is low. At lower relative humidity, air will absorb moisture from grains and store hence reducing grain moisture content. Thus it is necessary to regularly monitor the moisture content of the grain in store.

- Chemical Variables: the chemical variables are important in maintaining nutritive values and quality of grain. A balanced relationship between the food components such as water, fat carbohydrate etc. is important in maintaining its storage stability. Oxygen supply is the most important single variable that affects the growth and development of all harmful organisms that disturb this balance. Other chemical variables include fat and lipid content of the crop

- Biological variables this include respiration, post harvest maturity and sprouting of the crop and living organism in the stored grain.
- During storage, the grain and the microbial associates respire. The respiration of the microbial is more crucial in the deterioration of the grains. The direct effect of respiration is the loss of dry weight and gain in moisture content of the grain, rise in the level of CO_2 in the inter-granular air and rise in the grain temperature.
- This could cause sprouting of grains, moulding, increase in insect infestation and loss of quality and quantity of stored grain. Thus regular monitoring of the temperature and moisture of stored grain and ventilation is essential to minimise these losses.
- Post harvest maturity occurs within the first 60 days as a complex biochemical change. The variables crucial to this phenomenon are moisture, temperature and ventilation. The post harvest maturity stage is very important in enhancing viability of seeds.

Losses in stored grains:

loss is a measurable decrease of food product which may be qualitative or quantitative.

- Loss in quality occur in various forms which include change in colour, smell, taste, loss in nutritional value, loss in cooking qualities, loss in viability, contamination by toxins or pathogenic agents. Several of these qualitative losses can occur simultaneously usually in connection with weight loss.
- Loss in quantity of stored grains often result from damage of grain by insects, pest and rodents, by theft, leakages from damaged bags and loss in weight resulting from loss in moisture content of stored grain.
- Economic loss: is often a direct consequence of all quality and quantity losses or indirectly results from incurred in the process of preventing other losses.

- Factors responsible for losses and deterioration in stored grain
- Pre storage factors
- Physiological and metabolic deterioration: grains are living tissues which after harvest undergo physiological and metabolic activities. Such activities are affected by adverse environmental conditions such as high temperature or high or low relative humidity this cause physical damage to the grain and cause deterioration during storage.
- Infestation by micro organism and pest: while on the field grains can be infested by insects and after harvest are carried in to the store.

- Time of harvest: time of harvest have significant effect on their deterioration in store. Too early harvesting will lead to deterioration due to high moisture content while delayed harvesting will expose mature grain to insect infestation, rodent and bird attack on the field. These enhance deterioration in store.
- Mechanical damage: improper handling of food grains during harvesting and pre storage operations may cause internal and external bruises which will create sits for infestation, rapid loss of moisture and increase rate of physiological breakdown.

- Storage factors: storage factors that affect grain quality can be grouped in to two:
  - Climatic factors in the store (temperature and relative humidity of prevailing microclimate) and concentration of O_2 and CO_2 specially in hermetic storage
  - Properties of the grain which include physiological behaviour (respiration), moisture content heat conductivity .

- Respiration: grain is a living organism and it respires. The level of moisture in the grain influence the respiration rate. During respiration, oxygen and carbohydrate are used up to produce carbon dioxide, water and heat. An increase in storage temperature increases respiration rate further. Biological factors such as insects and moulds also respire and add to the moisture within store. The nutrient used up during respiration leads to loss in weight and texture of grains.

- Moisture content: moisture content is one factor that determines if mould growth on grains will occur or not. The water produced during respiration can be reabsorbed thus cause moisture fluctuation. This affects the overall weight of stored grain. When moisture content exceeds the safe storage limit, fungi, insect and mould infestation increases rapidly.
- Heat conductivity: grains have low heat conductivity, this makes heat fluctuation in store less noticeable within a short time. however, this property also means the rate of heat loss from grains is slow such that heat accumulation occur which in turn leads to increased respiration rate, higher insect infestation and condensation resulting from hot spot.

- Methods of loss estimation in stored grain:

Estimating losses in stored grain has been a difficult thing in developing countries considering the fact that most rural farmers do not have exact data on quantity of stored crop. Some methods adopted to estimate storage loss of grains are:

- Weigh-in weigh-out method: this method is used to assess losses in stored grain. It involves taking weight records of grains when being put into store and when being removed from store. The moisture content of the grain is taken simultaneously with weight so as to compare the total dry matter loss. The dry matter loss is expressed as a percentage of the initial value. This method give good result when used in threshed crops. However, when used for grains that are stored un-threshed the result usually are inaccurate and also removal of grains on daily or weekly basis affect the accuracy of the result.

- Thousand grain mass method: this method involves measuring the changes that occur in mean grain weight over a period of time under given storage conditions. Thousand clean grain kernels are selected at random from a grain sample, the mass is determined along with the moisture content and the mean dry weight is calculated. This is done at regular interval and the weight loss between time intervals determined. This method is simple and fairly rapid and does not require measurement of the entire bulk.
- Count and weigh method: using this method the mean weight and number of damaged and un-damaged grains is determined from the same sample. The proportion of damaged kernels is computed using the formula

$$\% \, weight \, loss = \frac{UN_d - DN_u}{U(N_d + N_u)} \, x \, 100$$

- where U is weight of undamaged grain, N_u number of undamaged grain and D is weight of damaged grain and N_d is number of damaged grain. The major limitation of this method is high sampling errors as a result of variability within samples. However it is a simple and rapid method of determining weight loss.

- Standard volume weight method (bulk density) method: the change in bulk density is used as an indicator of weight loss. This method requires that the bulk density of sound grains be determined over a range of moisture content prior to the use of this method. Samples of the same grains are then taken from storage and the bulk density determined and compared to that of sound grain at the same moisture content and weight loss computed as:
where ρ is the bulk density of the sound (s) and the damaged (d) grain.

$$\% \, weight \, loss = \left(\frac{\rho_{s} - \rho_{d}}{\rho_{s}}\right) x100$$

Classification of Grain storage techniques and methods

Methods of grain storage differ widely across different geographical locations, climatic conditions and socioeconomic life of the people. Grain storage methods can be classified based on duration, size and scale of storage and protection methods.

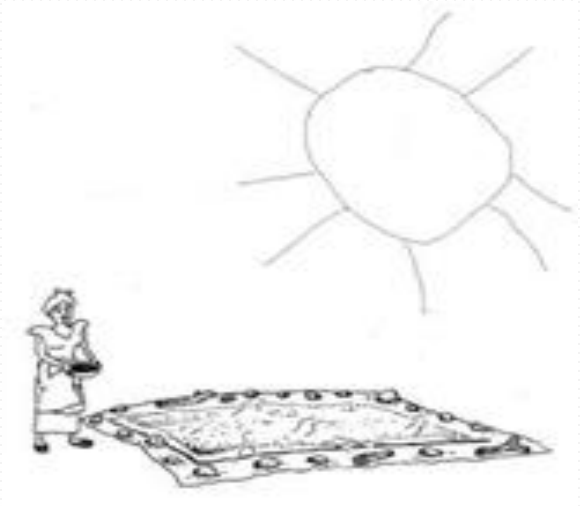
- Based on duration of storage it can be
- short term this is less than six months, they are often associated with the drying of the crop and intermediate storage structures. This could be aerial storage, platform storage etc
- medium term storage this is keeping the quality of grains for up to 12 months
- long term storage this are methods that can keep grain quality (viability and proximate characteristics) up to five years or more . Practiced generally by government agencies and research institutes

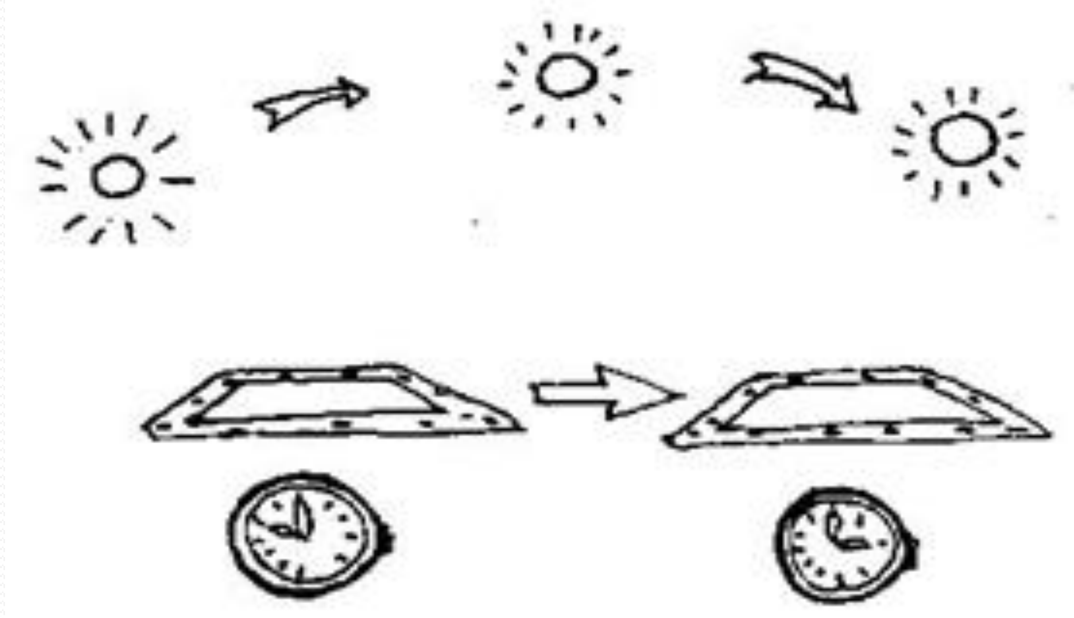
- Based on size and scale storage capacity can be
- Small scale storage: have a capacity below 2 tonne, particularly used for domestic consumption and farm level storage
- Medium scale storage: these have the capacity 3 – 100 tonnes. They are for large scale farmers, traders, exporters and agro based companies.
- Large scale storage: these are temporary or permanent storage structures with capacities above 100 tonnes, usually owned and operated by government or non government organizations

- Based on protection methods it can be
- Physical storage: in this method the physical environmental factors along with air flow are controlled and manipulated such that the activities and development of agents of deterioration are inhibited. Examples are hermetic storage, CA storage, aeration , ventilation, solaraisation and hermatic storage , cold storage etc..
- Chemical storage: this method adopt the use of chemicals to stop the actions and activities of pests in store
- Biological storage: this method adopts the use of biological products and agents such as predators, or plant extracts to retard the activities of agents of spoilage in stored grains.

Solarising grain to kill insect pests

- When grain is placed in a solar heater, it may be heated sufficiently by the sun to kill all insects, a process called solarisation.
- done with relatively small quantities of cowpea (25 to 50kg), since it is labour intensive, but it could also be done with other grain.
- It can reduce the viability of seed, should be used for food grain only The simplest type of solar heater consists of an insulting layer on which grain is laid to a maximum depth of about 2-3 cm, they are then covered with a sheet of translucent plastic and the edges of the sheet are weighed down with stones or other heavy items. The solar heater should be kept in the sun for at least 5 hours.
- After solarisation the grain should be allowed to cool before it is placed in store. If the grain is placed in an insect-proof container then it will remain free of infestation. If there is free access to insects (e.g. in an open weave sack) then after 2-3 months the grain may become re-infested. To avoid this, the grain should be retreated each month.





Important points to remember about using insect proof/hermetic stores

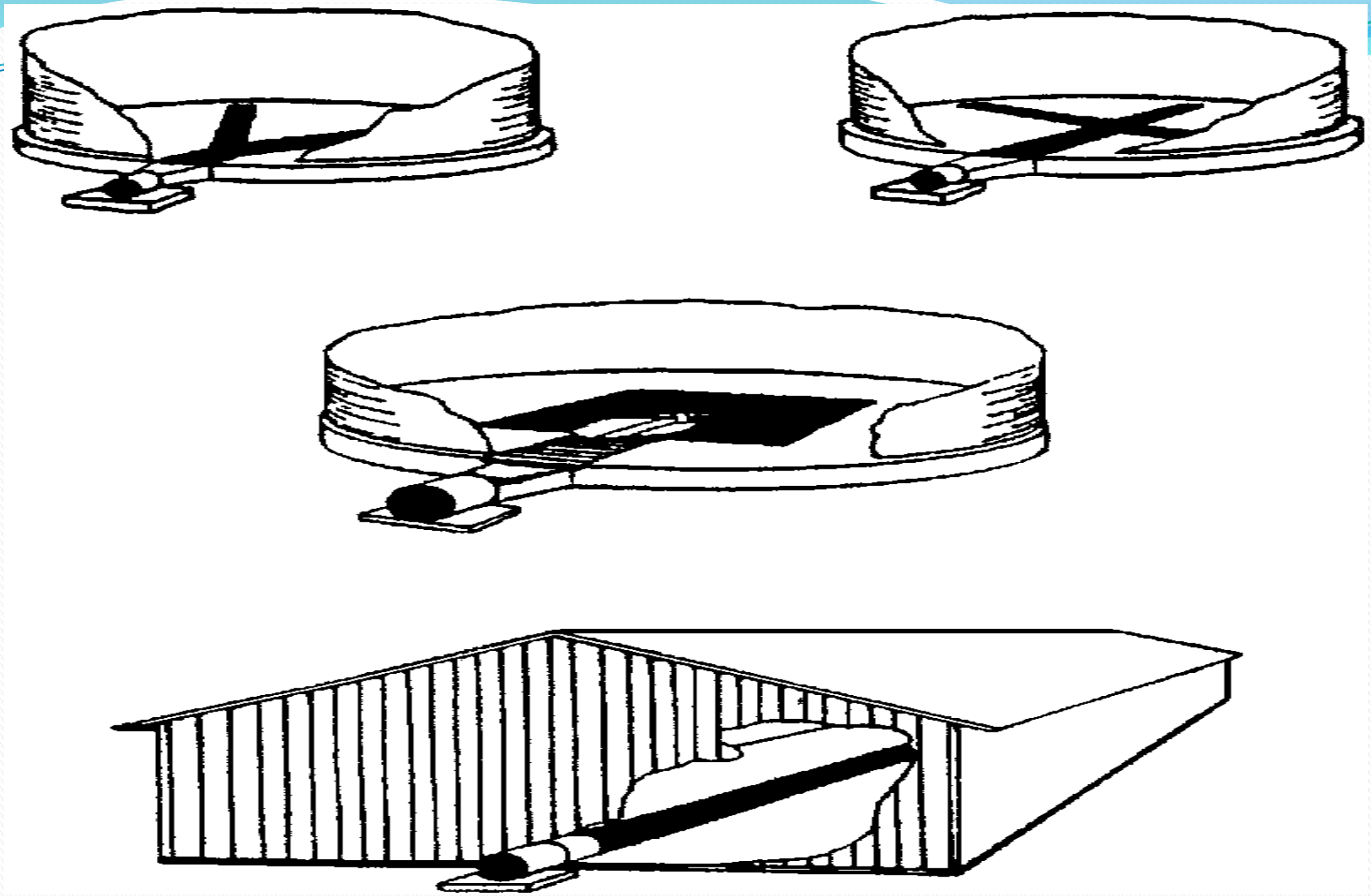
1) Grain to be consumed or sell within six week of harvesting should not be put in the sealed store but can be stored in open weave sacks and does not need to be treated with chemical grain protectant as few if any insects will develop during this short time.
2) When putting grain in well sealed or hermetic stores it must be at a safe moisture content (typically 14% or less depending on the crop).
3) the store must be check to make sure has no holes in it and it can be properly closed.
4) The hermetic stores must remain fully sealed for at least six weeks if natural deoxygenation is to be used, but in the case of metal silos where a lighted candle or fumigant has been used to deoxygenate the store then it should be kept closed for at least two weeks.

5) The store should be located inside the house (or at least completely shaded from the sun) and not near a fire. It is important that the store does not get too hot. If the store gets too hot on one side and remains cool on the other then there is a danger of moisture migration, this could lead to condensation on the cold side. Condensation of water on grain can lead to mould damage. Furthermore, if the grain is to be used as seed then its viability will be lowered if it is subjected to higher temperatures (especially if over 30°C).

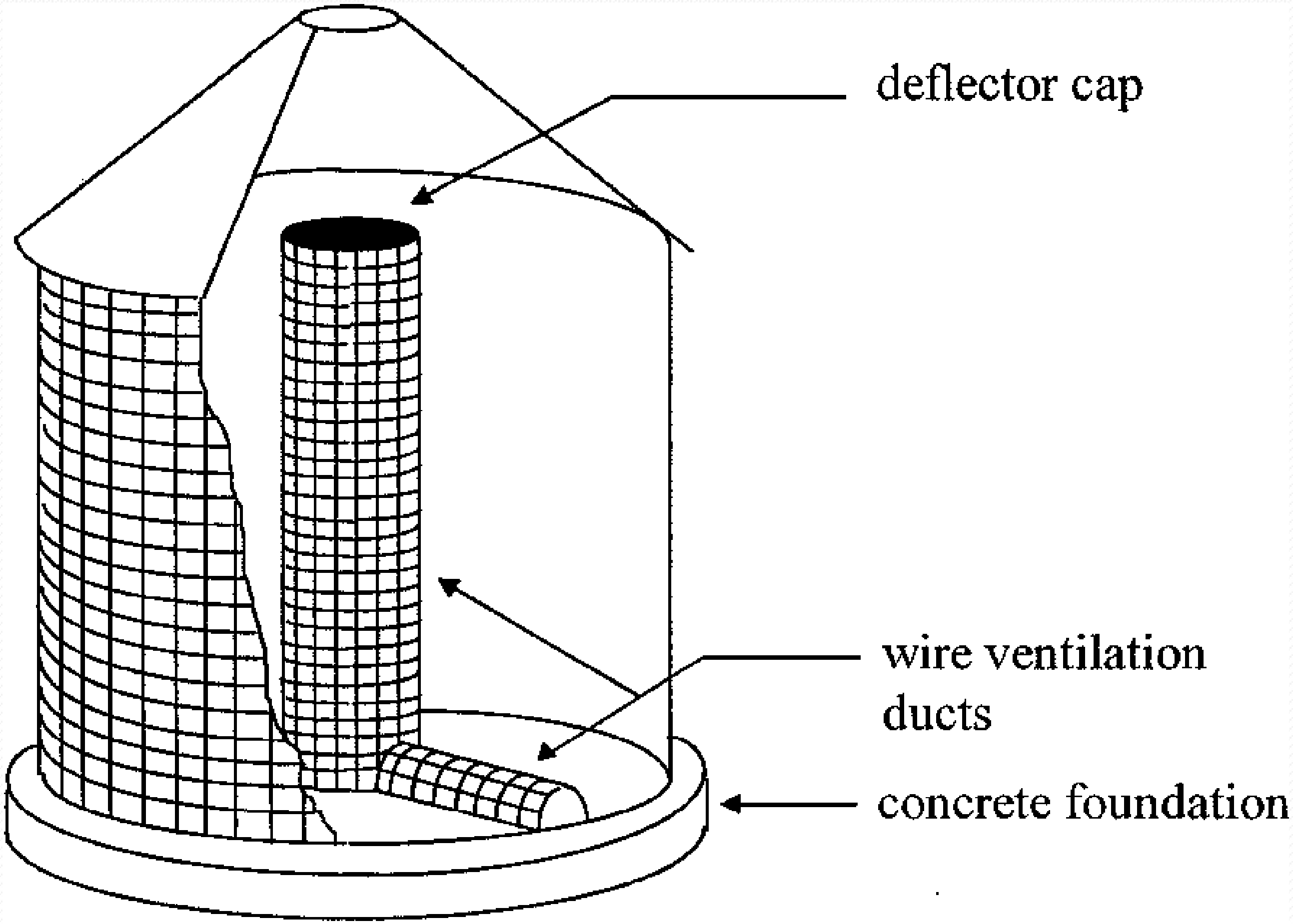
6) Hermetic store specially metal stores store should be kept off the floor as they may become damp and this would lead to corrosion. Place the metal store on a wooden or brick platform and this will prolong their life.

Aeration of stored grain

- Grain stored in bulk at initially low uniform moisture content will over time increase in moisture content at some locations in the bin.
- This phenomenon is caused by a low rate of airflow occurring in the bin, resulting from a temperature difference between the grain near the bin walls and the ambient air surrounding the bin.
- The so called natural-convection airflow currents lead to condensation and crusting of the grain, usually in the 0.3- to 0.5-m thick grain layer in the top-center of the bin.
- The detrimental effects of natural convection can be counteracted by minimizing the previously mentioned temperature difference between grain and air. This is the objective of the process of *aeration*, which is the intermittent moving of ambient air at low flow rate through stored grain.
- An aeration system consists of a fan, an air-supply duct, aeration ducts located in the bin (or a perforated floor), and an aeration controller.



Typical grain aeration systems


deflector cap
wire ventilation ducts
concrete foundation

Simple methods of deoxygenation of stored grains.

Deoxygenation is done to kill insects and all other living organisms in the stored grain.

- Use of lighted candle
- Can be used in metal silos
- must be completely sealed including inlet and outlet ports
- A lighted candle is placed on the grain surface
- The candle will burn the oxygen and create carbon dioxide
- When the oxygen is consumed and the light is extinguished, insects and other living organism will die within a week or two
- The silo should be kept sealed at least for two weeks

- The use of triple or double bags
- The triple bagging is widely used for the storage of cowpea, other pulses and cereals.
- There are two inner bags made polyethylene and one outer more durable bag to help protect against damage.
- The first bag is filled with grain at a safe moisture content for storage which is tied shut securely using string. The first bag is placed within a second bag and this is closed securely.
- A third bag is used to enclose the first two and to protect against damage;
- the third bag can be made of open weave polypropylene. It is recommended that the two inner bags are made of clear plastic so that the grain can be easily seen for any signs of insect attack.
- The bags should remain sealed for at least six weeks after they are filled and after opening they should be resealed quickly to prevent entry of pests.
- Triple bagging is easily adopted by farmers, provides a very high level of insect control, and the bags may be used for as long as 3 years before they become too damaged and so need to be replaced.
- To reduce cost it can be made of only one polyethylene bag(double bag)

Use of double or triple bags

Use of chemical fumigant

- Stored grains can be fumigated with phosphine gas (generated from aluminium phosphide tablets)
- However, manufacture's recommended procedure must be followed

Storage of root crops

- Root crops belong to the group of semi-perishable goods, that is, product with a high natural moisture content.
- These products are more sensitive to quality loss than cereals because conservation using drying techniques may not be applied.
- Storage of root crops reduces the seasonal character of crop availability for the fresh market or for the food industry. Most products are harvested during a specific season that may last several months, but the consumption of these staple foods can occur all year round.
- Storage of a root crop has economic advantages, as it extends the processing season and keeps the processing plants running continuously.
- It also helps food processors bridge short-term periods of low supply of freshly harvested products.

- **Plant parts utilized as food are derived from virtually every portion of the plant.**
- Food items derived from below the ground part of the plant are called Roots, tubers, and bulbs.
- These parts serve as storage organs, containing products accumulated during photosynthesis.
- Roots are storage organs which are modified roots that contain starch and sugar reserves, examples of root are carrot, Cassava and sweet potato.
- Tubers, are underground parts that are anatomically the tip of a stem or rhizome with the appearance of a root. The stored reserves are mostly starch with some sugars and proteins, examples of tubers are potato and yam.
- Bulbs are modified buds consisting of a thickened globular underground stem serving as a storage organ and a reproductive structure



Root Crop Quality and Losses

- The storage loss for roots and tubers in developing countries vary from 5% to 100% depending on the crop, storage period and storage methods.
- The main causes of product loss in root and tuber storage are **mechanical injury**, **losses due to diseases**, **attacks on stored products by rodents or insects** and **physiological losses.**
- Good agricultural practices before, during and after harvest can minimize losses due to the first three causes. However, physiological losses are as the result of respiration, loss of moisture (transpiration) and heat transfer.

Product respiration

- Respiration is a central process that occurs in all living cells; it is essential for the maintenance of life in products after harvest.
- The substrates used are oxygen and stored carbon compounds, such as starch.
- Carbon dioxide, water, and energy are the end products released into the surrounding atmosphere,
- The overall effect is a loss in weight of the stored product. A simplified representation of the process is:
- $C_6H_{12}O_6 + 6O2 \rightarrow 6CO_2 + 6H_2O + 2667$ kJ energy

- As there is little cell development or growth in stored products, the respiration energy is mainly in the form of heat.
- The measurement of the respiration rate can be based on concentration changes in any of the reactants or products involved in the process. In general, oxygen utilization or carbon dioxide production is used, because these can be measured with relative ease and adequate accuracy.
- The respiratory activity of plants is strongly affected by a number of **crop factors** and **environmental factors**. Because the end quality of a stored product is a direct result of the respiration activity, it is mandatory to have a proper management and control of these factors in order to optimize storage life.

The most important **crop factors** are

- *Species and Cultivars* Although differences in respiration rate may be expected between species, there may also exist substantial differences among cultivars, resulting in differences in their storage potentials.
- *Moisture Content*: In general, metabolic processes slow down with decreasing moisture content. However, decreasing the moisture content of fleshy products like roots or tubers is not an attractive method to control respiration, because moisture content is closely related to product quality.
- *Surface and Volume Properties:* The respiration rate of a product is usually proportional to the product mass. However, gas exchange with the environment occurs at the product surface, and the surface-to-volume ratio can play an important role when considering the appropriate storage conditions. In addition, the gas-diffusion properties of both the fleshy tissue and the surface tissue are important.

- *Stage of Development at Time of Harvest* The product composition in general is affected by the stage of development and in turn may affect the respiratory behavior. This explains, in part, differences in final quality that exist among crops harvested at different locations but stored in the same storage room.
- *Wounding* The respiratory activity of wounded plant tissue increases because of an increase in the required healing substances such as lignin, suberin,
- Infection of the wounds by microorganisms also increases the respiration because of defense reactions by the cells. In addition to these effects, wounding also alters the gas diffusion resistance of the product surface.

Environmental Factors

- *Temperature*
- An increased temperature results in increased reaction rates; not all reactions have the same change in rate with temperature.
- The change in respiration rate due to a change in temperature represents the overall effect of temperature on the different chemical reactions of the respiration process.
- Keeping the product quality throughout a storage period as near as possible to the quality at harvest time requires that the metabolic processes be slowed down as much as possible.
- This is best achieved by storage at low temperature, provided that no other adverse effects, such as cell-membrane damage, occur at low temperatures.
- Different equations have been proposed to express the temperature dependency of the respiration rate. One such measure is the Q_{10} value, the ratio of the respiration rate at one temperature (T_1) to the rate at a temperature 10°C higher:
-

$$Q_{10} = \frac{Rate\ of\ x_1 + 10^{o}C}{Rate\ of\ x_1}$$

- For many products the Q_{10} value for respiration is between 2.0 and 2.5 in the temperature range between 2°C and 25°C.

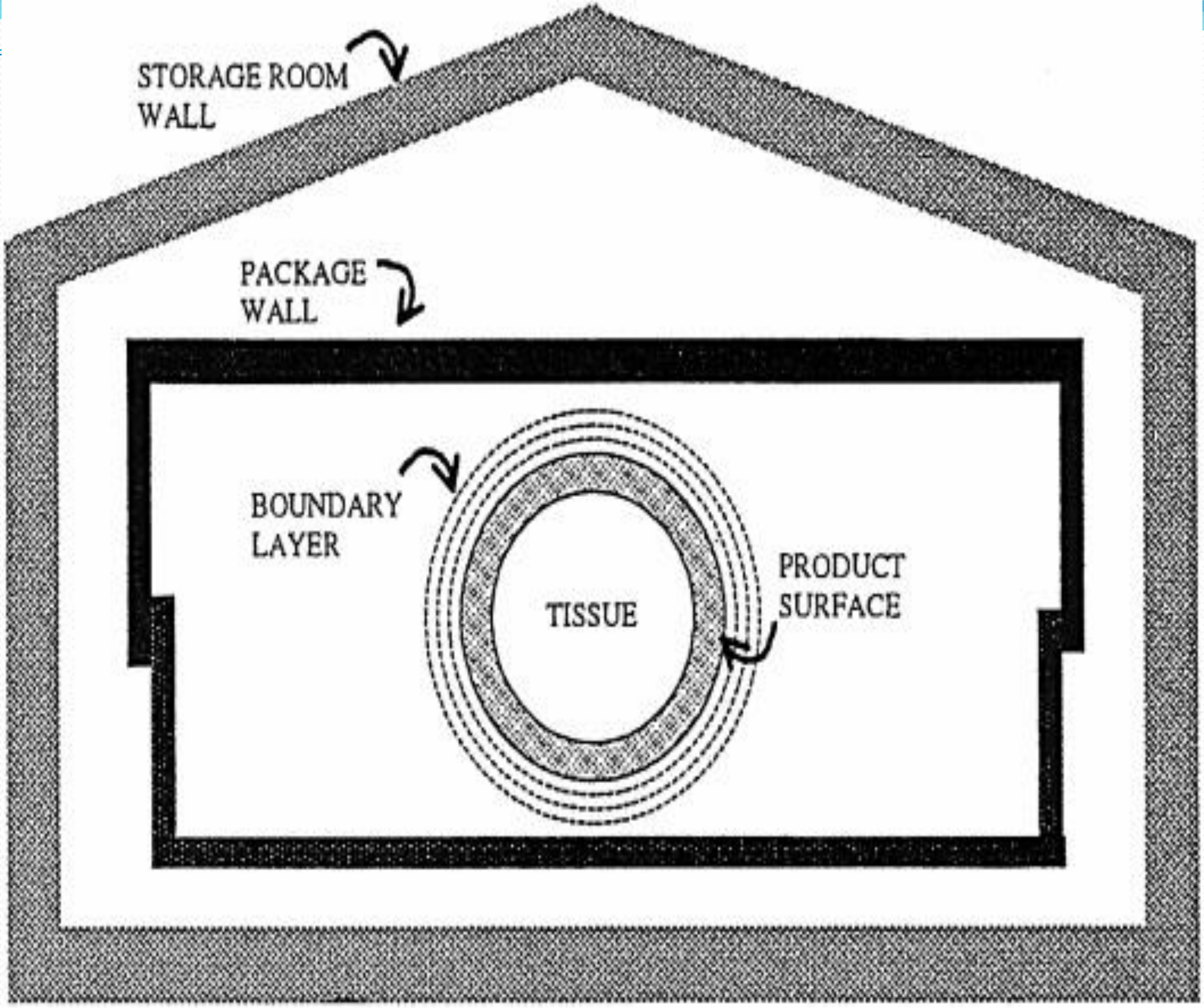
- The rate of heat generation by respiration, W_{resp} (J/ $kg^{-1}h^{-1}$), can be approximated by $W_{resp} = 10.7mCO_2$

where mCO_2 is the carbon dioxide production per unit mass of a product (mg kg^{-1} h^{-1}), and it is estimated as

$$mCO_2 = f(\frac{9T_m}{5} + 32)^g$$

- where = Tm is the mass average product temperature (°C), and f and g are respiration coefficients which depend on the crop.
- Even at low temperatures the product is still characterized by a low metabolic activity, and subsequently heat is still generated.
- This internal heat generation in the product causes the product temperature to be slightly higher than the storage-room air temperature. This may not have a large effect on the respiration activity, but it can greatly affect the vapor-pressure difference between the product and the surrounding air, thus influencing the moisture balance of the product.

- *Gas Composition*
- The gas composition of the atmosphere in which a root product is stored has a strong influence on the respiratory activities of the product.
- There is a significant difference in gas composition and diffusivity between growing and storing conditions.
- This has an influence on the gas-exchange rate, and therefore on the metabolic activity of the tissue.
- An overview of the different resistances to gas exchange between product and ambient air is given in Fig below.


STORAGE ROOM
WALL
PACKAGE
WALL
BOUNDARY
LAYER
TISSUE
PRODUCT
SURFACE

- Resistances to gas exchange in a harvested and stored product include
- storage walls,
- package wall,
- boundary layer,
- product surface,
- and tissue.
- The resistances of storage walls, package walls, and product surfaces are often manipulated for postharvest products to extend storage life.

- The respiratory activity of most stored root products decreases substantially if the external oxygen concentration drops below 10%.
- At very low oxygen concentrations, anaerobic metabolic processes start. For sweet potatoes, for example, this may already be the case between 5% and 7% oxygen.
- Of course, the internal diffusion resistance and the rate of oxygen consumption are also controlling elements for the internal oxygen concentration.
- An increased concentration of carbon dioxide in the ambient air has an effect on several biochemical processes, slowing down the overall respiratory activity.
- However, this effect may not be the same in all tissues or at all carbon dioxide concentrations.

- Temporary exposure of the tissue to increased but commonly used carbon dioxide

  levels also slows down the respiration rate; this effect vanishes when the carbon dioxide concentration is reduced to normal values.
- Note that, similar to oxygen, the carbon dioxide level in the tissue is the result of the respiratory activity, the diffusion resistances, and the ambient concentrations.
- Ethylene is a plant hormone that can significantly affect the respiratory activity of
- plant tissues. Because most stored products produce ethylene, accelerated respiratory activity ensues if this hormone is allowed to accumulate in the storage room.

- ***Transpiration***
- Transpiration of root crops is a mass transfer process in which water is lost from the product.
- It involves the transport of moisture through the outer layers of the product, the evaporation of the moisture from the product surface, and the convective mass transport of the moisture to the surroundings.
- Moisture loss affects the product quality, causing changes in appearance (the surface starts to shrivel), texture, and flavor.
- In addition, moisture loss also reduces the mass of salable product.
- The driving force for transpiration is the vapor-pressure difference between the surface of the product and the surrounding air.

- The basic mathematical model to describe transpiration is given by:

$$m_w = k_t(P_s - P_a)$$

- where m_w is the moisture loss per unit product surface, P_a and P_s are the vapor pressure in the surrounding air and at the product surface, respectively, and k_t is the transpiration coefficient.
- To take into account the skin resistance of the product and the effect of airflow rate, the transpiration coefficient is modified as follows:

$$\frac{1}{k_t} = \frac{1}{k_s} + \frac{1}{k_a}$$

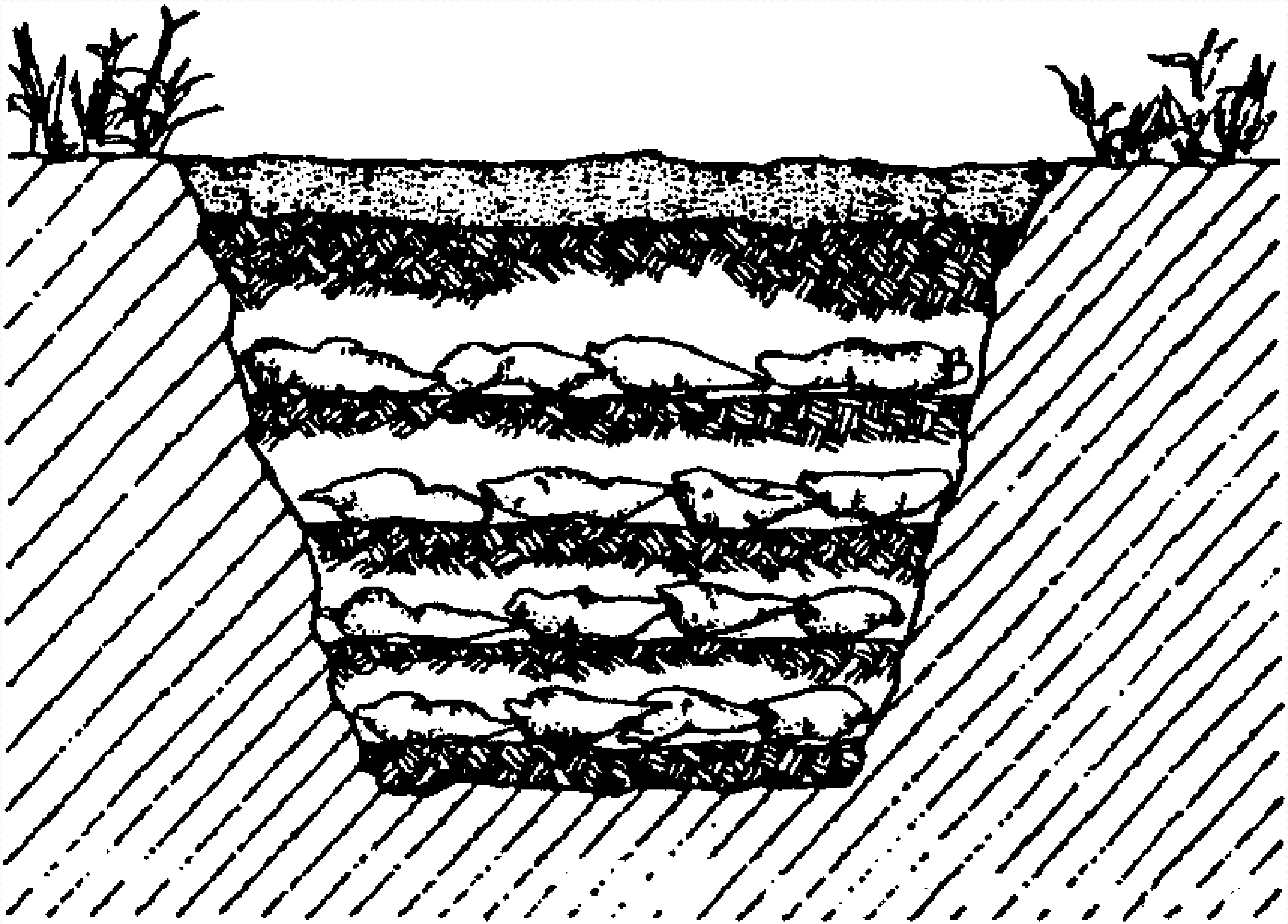
- **Heat Transfer of Root Products**
- It has been mentioned that the product temperature influences the metabolic processes of respiration and transpiration.
- As a consequence, the temperature history of the product affects the quality of the product after storage.
- One of the most important steps after harvest is the removal of heat stored in the product.
- Indeed, at harvest time the product is at a temperature at which the respiration rate is high and the quality degrades rapidly. Thus natural cooling of the crop after harvest under natural convection is important.
- The amount of heat transfer during cooling and storage depends of the temperature difference between the tuber and the surrounding, thermal properties of the crop and geometrical description of the crop.

Storage of cassava tuber

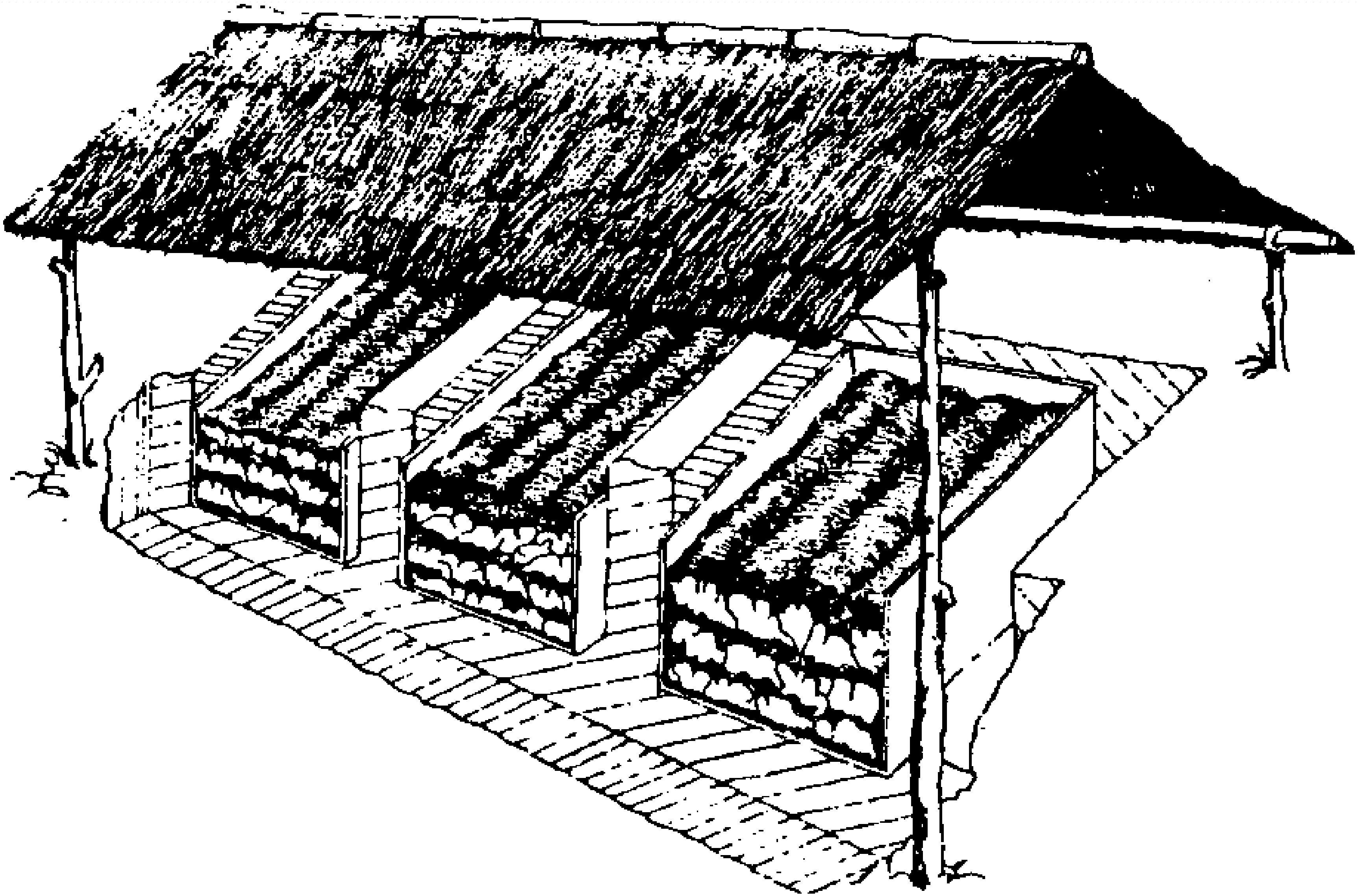
- Fresh cassava roots are highly perishable and can suffer serious physiological deterioration within 24 hours after harvest.
- The harvested roots are sold or processed immediately.
- Fresh cassava roots can be stored in the ground by delaying harvest of mature crop until needed.
- Roots also can be harvested and reburied in a cool place for short storage or held in modified environments in specially built storage structures.
- A moist storage environment is essential to control primary deterioration.
- Cassava roots store fairly well under refrigeration. Cassava is the only root that tolerates low temperatures and can be stored at 0 to 2°C for up to 6 months.

- Two low-cost structures that can be implemented successfully by farmers and processors are trenches and boxes containing sawdust.
- In either structure it is recommended that cassava roots should be harvested undamaged with about 14 to 20 cm of stem attached.
- Regular inspection and regular moistening at least once a week with clean water is essential.
- In this structures can be successfully stored for 6 to 8 weeks.
- Modern methods, such as refrigeration, deep freezing, waxing, controlled atmosphere and chemical treatments, have been suggested for the storage of fresh cassava.
- Freezing and waxing have been used primarily for export markets to Europe and America,
- These techniques require specialized equipment and skills and are very capital intensive.

Cassava stored in trench with complete soil cover.



Fully filled trench under thatch shed.

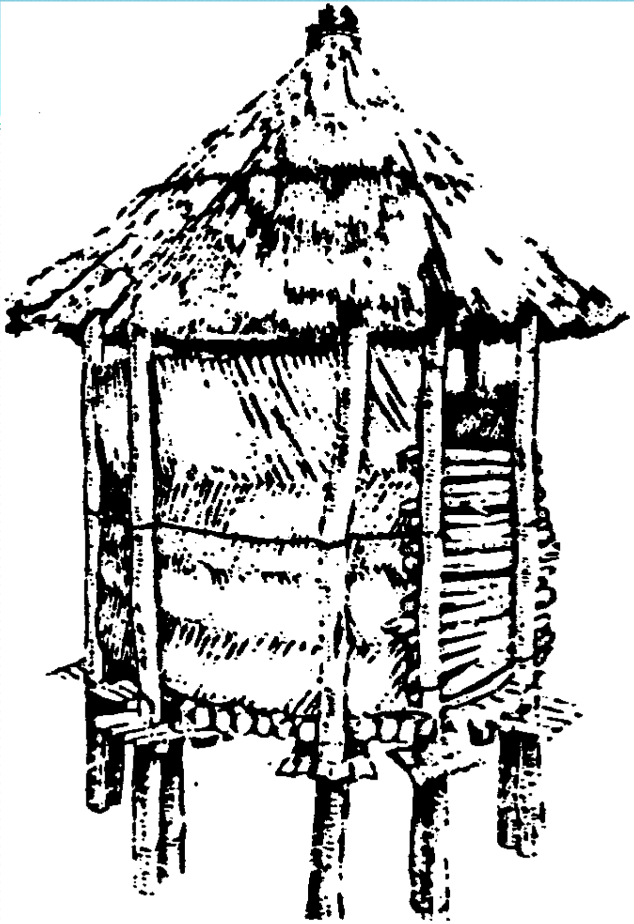


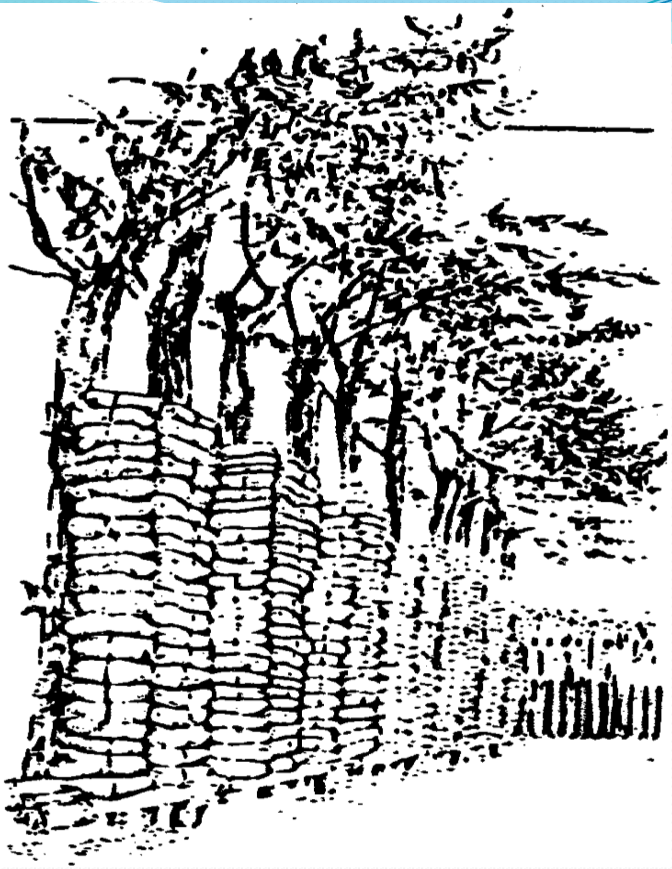
Yam storage methods and structures

- Yam tubers need to be properly cured as soon as possible after harvest to promote the formation of a hard cork layer.
- Curing should be carried out near the place where the tubers will be stored to minimize handling after curing. The process is carried out for 4 to 7 days at temperatures of 32° to 40°C and a relative humidity of 85% to 95%. Farmers achieve these conditions in two ways:
- **Above ground**. Yams are carefully piled on the ground and covered by a layer of grass at least 15 cm thick and finally a canvas tarpaulin or jute bags are used to cover the whole pile. Plastic sheets should not be used and the curing pile should not be exposed to direct sunlight. The cover should be removed after 4 days.

- **Pit-curing**. This consists of a pit, with the bottom lined with sawdust or dry grass. The yam tubers are placed on this lining and then covered with a layer of soil. The treatment takes about two weeks after which the tubers can be removed for storage.
- According to trials in Nigeria, yam tubers treated for two weeks by this method showed only 40% rotted tubers after 4 months of storage, compared to 100% of untreated tubers.
- Under favourable environments, yams can be stored for several months and some cultivars for longer, but loss in flavour and quality occurs in storage.
- The three main requirements for yam storage are aeration, reduction of temperature, and regular inspection of produce.

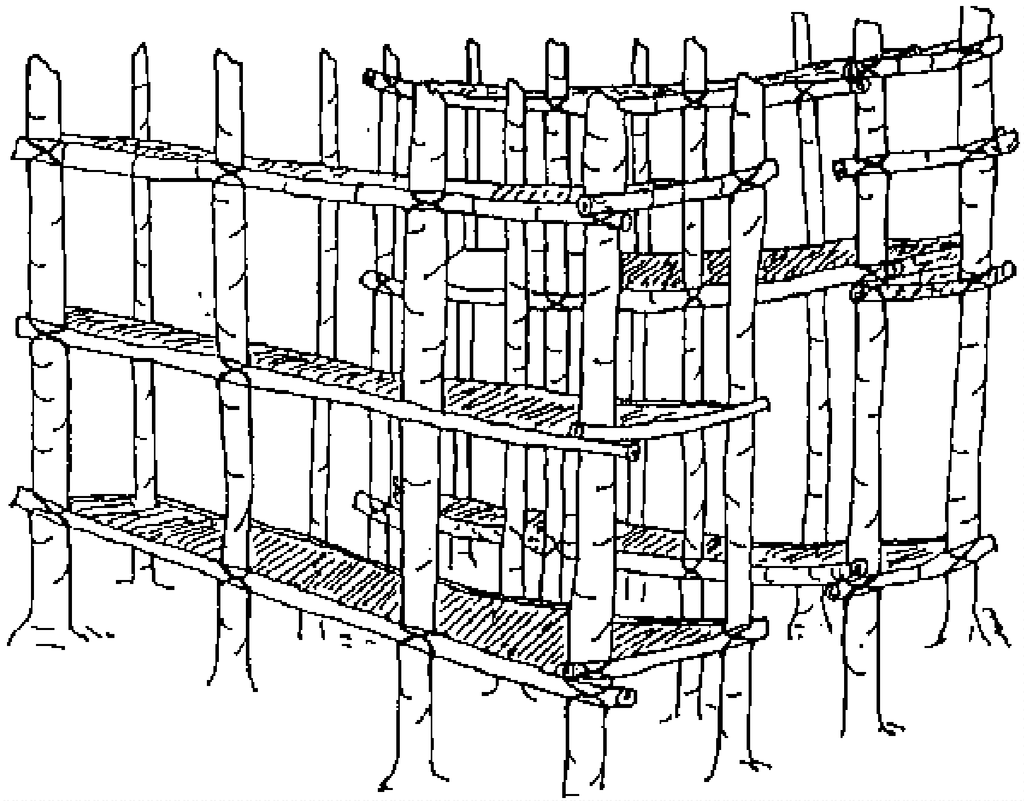
- Aeration prevents moisture condensation on the tuber surface and assists in removing the heat of respiration.
- Low temperature is necessary to reduce losses from respiration, sprouting, and rotting; however, cold storage must be maintained around 12 to 15^{o}C, below which physiological deterioration such as chilling injury occurs.
- Regular inspection of tubers is important to remove sprouts and rotted tubers, and to monitor the presence of rodents and other pests.
- In general, tubers should be protected from high temperatures and provided with good ventilation during storage. The storage environment also must inhibit the onset of sprouting (breakage of dormancy), which increases the rate of loss of dry matter and subsequent shrivel and rotting of tuber.
- Yams are stored in yam houses and yam barns. However, the mode of storage differs in different climaticall areas of West Africa.



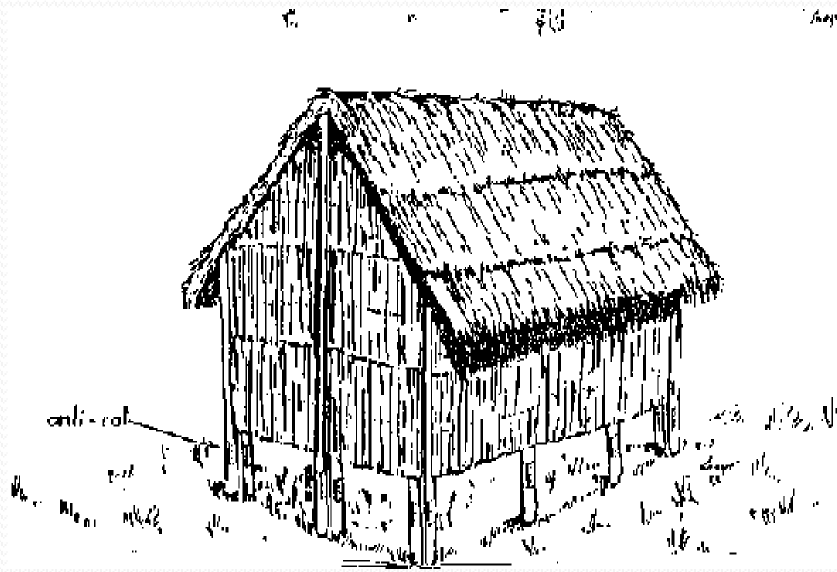


Inside view of a yam barn (humid tropics).

Traditional "yam house." (Savannah region)



Simple wooden shelves for yam storage



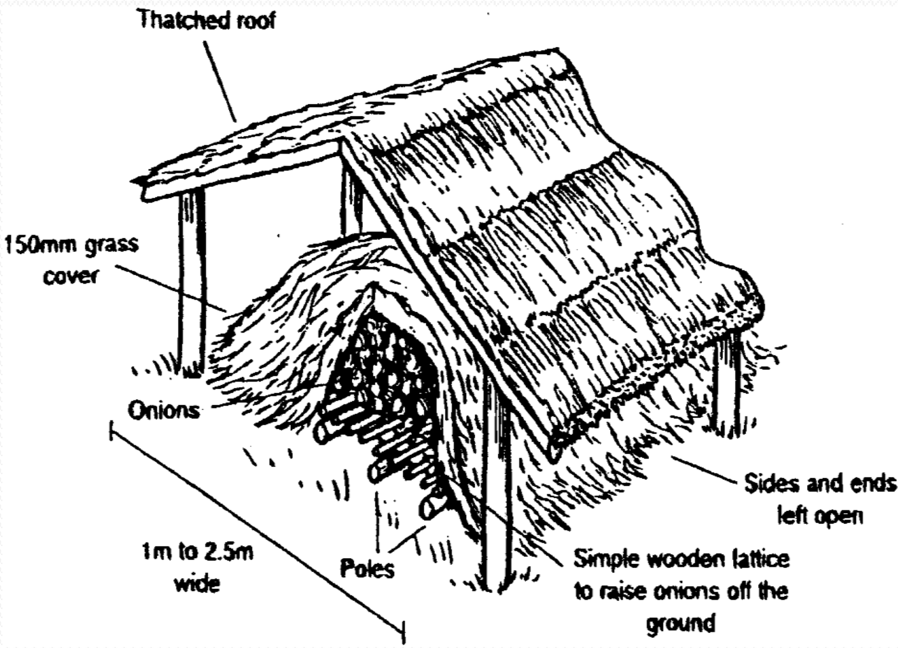
and elevated shed store.

Onion storage methods and structures

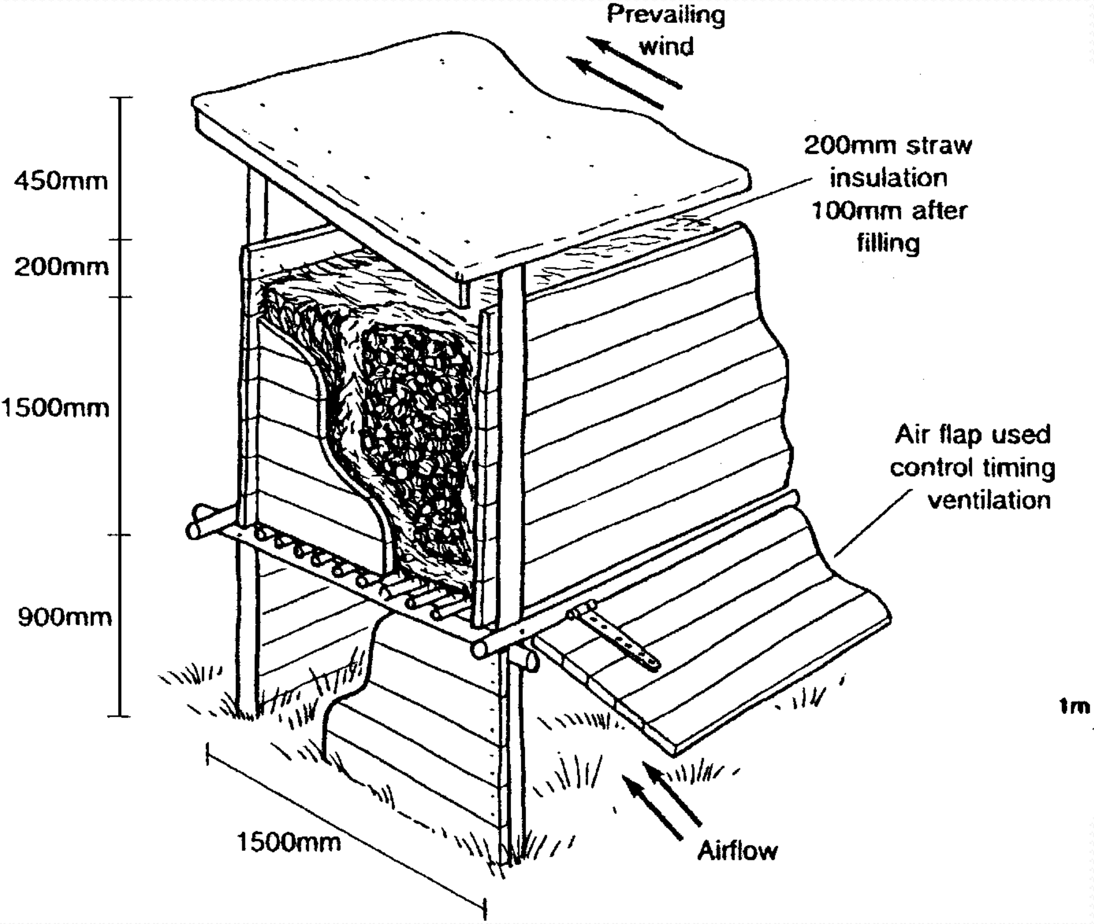
- Onions (*Allium cepa* L.) are highly valued worldwide for their flavour and for their nutritional value in supplying minor constituents such as minerals and trace elements.
- Prior to storage, the crop must be cleaned and graded, and all damaged or diseased bulbs removed.
- Careful harvest and pre-storage treatment with minimal mechanical loads are important to achieve a long storage period.
- Storeroom temperature, relative humidity, and atmospheric composition influence the length of storage that can be achieved without significant storage losses and reduction of bulb quality.

- Onions storage can be ***Low-temperature Storage, high temperature storage and control atmosphere storage.***
- For successful low-temperature storage, good ventilation and a low humidity level is essential. For large-scale commercial storage, onions usually are stored under refrigeration, and the most commonly recommended conditions are 4^{o}C with 70% to 75% relative humidity.
- Onions also may be stored at high temperatures of over 25^{o}C at a range of relative humidity's (75% to 85%) that are sufficient to minimize water loss. Storage at temperatures of 25 to 30^{o}C has been shown to reduce sprouting and root growth compared to cold storage.
- A range of CA compositions in combination with cold-storage temperatures can be used for storage of onion bulbs. However, high carbon-dioxide (1%–5%) and low oxygen (1%–3%) levels in combination with low-temperature storage have been shown to reduce sprouting and root growth.

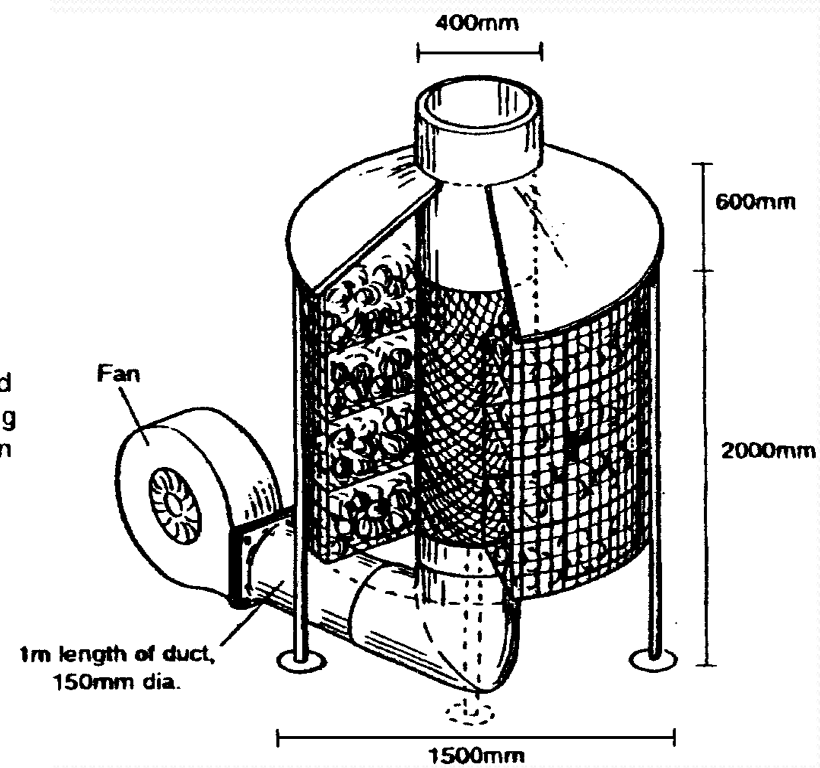
Onion store built from straw.



Cover clamps raised from the ground



Improved naturally ventilated onion store.



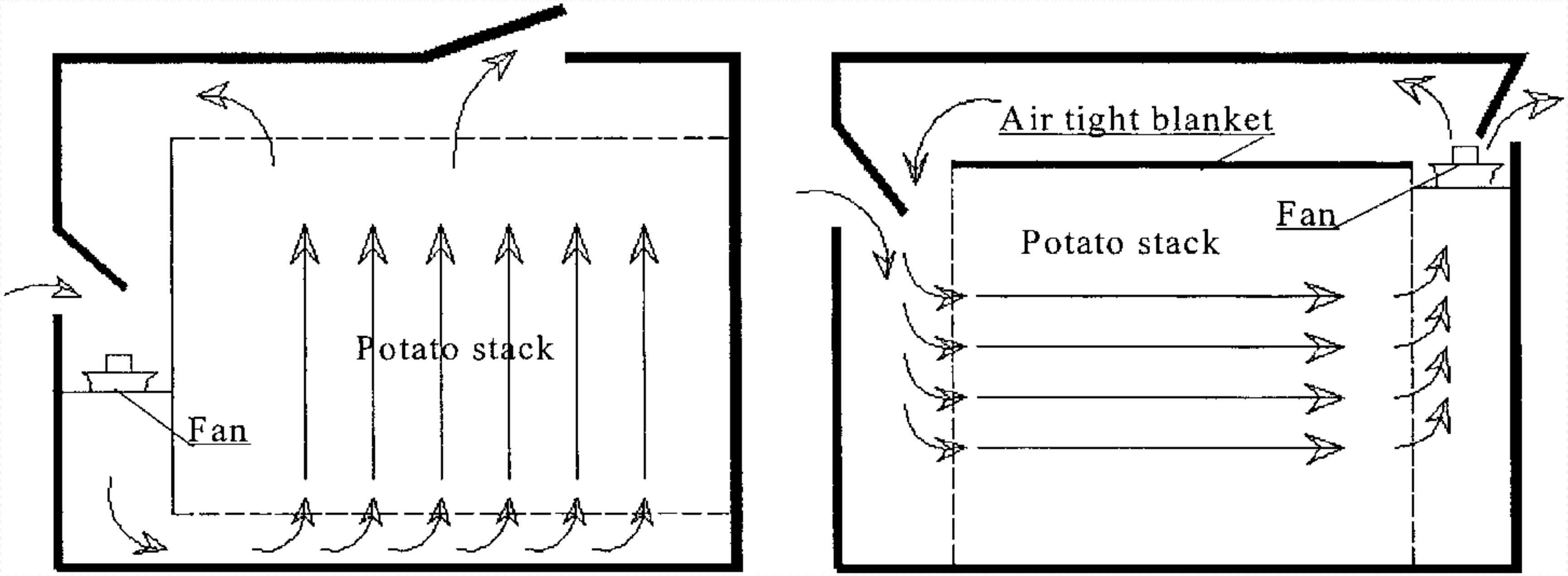
Forced-ventilated onion store

Potato storage methods and structures

- In long term potato storage process the following phases are identified:

- I. Drying of wet product or removal of free water
- II. Suberization or wound healing (curing)
- III. Gradual cooling down to storage temperature
- IV. Long-term storage or holding period
- There are three different methods of potato storage: underground storage (extended harvest), storage without buildings in heaps and storage in buildings.
- In storage without buildings the crop is predominantly ventilated naturally.
- Storage in buildings can be bulk storage, storage in crates, and storage in sacks.
- Stores can be ventilated mechanically or naturally. Bulk storage can be vertically or horizontally ventilated

Aeration in bulk storage of potato



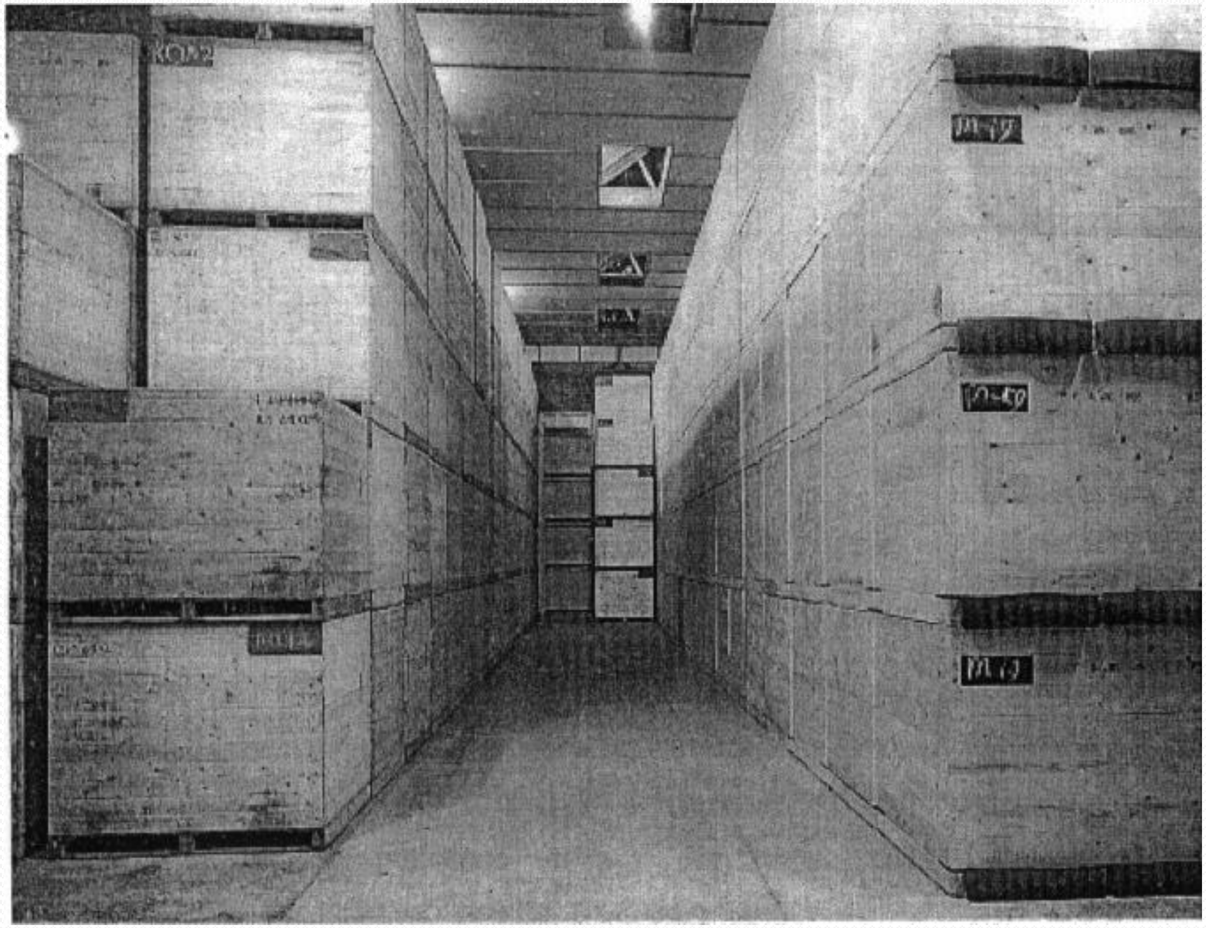
- In bulk storage the aeration system is less complicated and cheaper, because an air-distribution system can be omitted.
- Although total airflow, for equal storage capacity, is the same for horizontally and vertically ventilated bulk stores, the average air velocity in the bulk, and the pressure head are generally higher in horizontally ventilated bulk stores than in vertically ventilated bulk stores.
- This storage type holds the majority of today's potato harvest in the Western countries.

- Risks and problems with bulk stores are
- A bulk height of 4 m or more can cause quality deterioration by bruising and black spots.
- Ventilation and cooling are not always fast enough, thus possibly causing weight and quality loss (soft rot, pathogen diseases).
- Separated storage of different lots, verities, and selections, as is common with seed potatoes, is difficult.
- To prevent black spots induced by product handling, potato temperature must be
- 12°C or higher for sorting, packing, and transport operations. Bulk stores do not allow partial heating of a stored bulk.

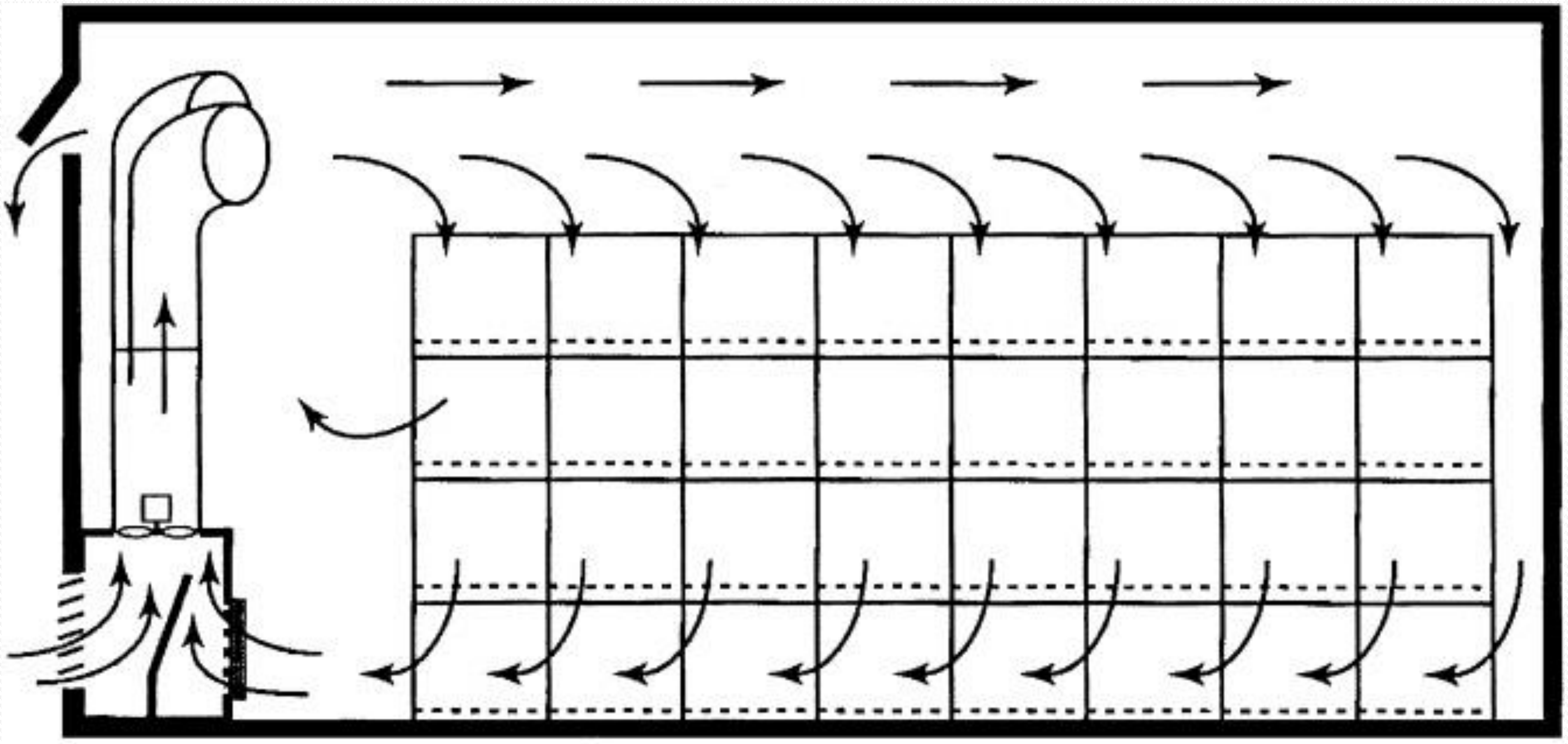
- For seed potatoes and potatoes for fresh consumption, crate storage in standard, 1-metric-ton crates is used.
- Different varieties and lots can easily be managed for intermediate checking or handling.
- The effective stack height is the height of one box. Appropriate box sizes are (l x w x h =) 1.10 x 1.40 x 1.24 m.
- With crate storage drying can progress faster, resulting in a smaller chance of diseases and bruises. A better product quality may result.
- The crates have closed side walls, The crate floor is perforated to allow air to flow through. The pallet bottom functions as an aeration channel. Stack height is up to five crates.

Crate storage system for potato

Crate storage system with flow-through ventilation system.



Aeration in stack storage of potato



Fruit and Vegetable Storage

- Fruit and vegetables are highly perishable and it is important to understand the biological factors that influence deterioration.
- An understanding of these features will improve farmer's ability to deliver high quality produce to markets.
- Horticultural products are susceptible to physical, pathological, and physiological deterioration.
- Both physical and temperature abuse of produce can lead to increased decay.
- Optimum storage temperature for some crops is 0°C, but for crops sensitive to chilling it may be as high as 16°C.
- Optimized refrigeration and controlled-atmosphere storage conditions reduce respiration, achieving slower deterioration and enhanced storage life.

- Post-harvest technologists attempt to maintain quality through the cool chain,
- They seek to control the handling, transport, and storage conditions to ensure optimal quality.
- Freshly harvested horticultural products remain alive after harvest, in contrast with other food products
- Horticultural products are very active metabolically, as reflected in their relatively high respiration rate.
- After harvest, horticultural products do not remain in a constant condition but continue to develop through the following processes that are genetically predetermined:
- maturation => ripening => senescence => death

- The developmental processes of maturation and ripeness merge and overlap. Maturity may have two aspects,
- *Physiological maturity* refers to that stage of development when maximum growth has occurred and proper completion of subsequent ripening can occur even if the product has been harvested.
- *Commercial maturity* is that stage of development of a fruit or vegetable that is required by the market.
- Deterioration commences at harvest;
- post-harvest technologies are designed to slow the rate of ripening and senescence and hence quality decline. Deterioration results from three main types of effects: physical, Pathological and physiological

- ***Physical Effects:*** Produce can sustain mechanical or physical damage at all stages of the chain from harvest to consumption as a result of poor handling or inadequate packaging.
- Such damage dramatically increases water loss and susceptibility to infection by post harvest fungi and bacteria.
- In addition, respiration and ethylene production are enhanced in wounded tissue; these all lead to rapid quality loss in physically damaged organs.
- Both product firmness and water status influence susceptibility to mechanical damage.
- Development of gentle yet effective handling systems and appropriate packages, together with education of personnel, are required to minimize physical damage.

- ***Pathological Effects:*** Post-harvest decay of produce results in major losses of horticulture foods worldwide.
- A wide range of fungi and bacteria contribute to post-harvest losses in fruit and vegetables throughout the world.
- These postharvest pathogens may infect produce at various pre-harvest stages through plant or fruit development, at harvest, or after harvest while products are in store or in transit to market. Any physical damage to produce provides an ideal entry point for such pathogens.
- A range of chemicals, applied both as pre-harvest sprays and postharvest dips or drenches are used against pathogens, but increasingly markets are not accepting such treatment. Recent consumer resistance to spray residues has led to development of nonchemical or biological control methods to combat postharvest fungal pathogens. Naturally occurring yeasts seem promising for reducing several widespread postharvest pathogens.
- Growth of many post-harvest fungi is inhibited or markedly reduced at storage temperatures below 5°C.

- **Physiological Factors** The physiological factors involved in deterioration of stored fruit and vegetables are respiration, transpiration and ethylene production
- ***Respiration***
- All living things respire to generate energy for continued metabolism. Respiration is highly temperature dependent. The lower the temperature of harvested fruit and vegetables the lower the respiration rate. Rapid cooling as soon as possible after harvest (to reduce respiration rate) is used commonly in the horticultural industry. Hydro-cooling, forced air-cooling or a well-ventilated shade is used widely to remove field heat rapidly. The amount of energy required to reduce the temperature of 1kg of a product by 1°C is given by its specific heat.
- Specific heat of food stuff can be estimated if the percentage of water in the food is known. If the percentage of water in the product is *p* then:

$$Specific\,heat = 4.19\,p/100 + 0.84(100 - p)/100\ (kJ/kg\,^{\circ}C)$$

- Estimate the amount of energy required to reduce the temperature of 1 tonne of mango harvested at 70% moisture content from 32°C field temperature to 16°C storage temperature
- Specific heat of mango at 70% mc = 4.19x70/100 + 0.84(100-70)/100 = 3.185kJ/kg°C
- Heat required = specific heat x temperature difference x weight 3.185 x (32 – 16) x 1000
- = 50,960 kJ

- ***Transpiration***
- Water loss through transpiration is a common occurrence in stored fruit and vegetables.
- In high moisture crops the product possesses a higher water potential than the air and that moisture migrates from a high water potential to a low water potential. It is therefore clear that moisture in a fruit and vegetables migrates towards the surface, where it subsequently evaporates into the surrounding air.
- Transpiration causes shriving, weight loss and loss of attractiveness in the market.

- ***Ethylene production***
- Ethylene is naturally occurring gaseous compound produced by plants that at very low concentrations can influence many aspects of plant growth and development. It is particularly important in the maturation, ripening and senescence of fruits, flowers and vegetables. Ethylene can have both positive and negative effects on product quality. Positive effects include:
- Coordination of several ripening events
- Induction of colour change from green to yellow
- Induction of softening, juice and flavour, development,
- Promotion of uniform ripening which help in commercial ripening of avocados, bananas and tomatoes

However, important negative effects of ethylene on quality include

- Accelerated senescence even at low temperatures
- Induced loss of green colour in leaves
- Induction of abscission in flowers and fruit
- Increased organ softening even at low concentrations.
- Induction of some physiological disorders
- Initiation of ripening in climacteric fruit that cannot be reversed.

- Horticultural crops are categorized as climacteric or non-climacteric depending on their response to and ability to produce ethylene.
- Climacteric fruit are those that produce relatively large amounts of ethylene during ripening on or off the tree. Peak production generally coincides with a concurrent respiratory peak within 3 to 10 days of harvest, after which respiration may decline. However, reducing the storage temperature greatly reduces ethylene production and ripening process.
- Non-climacteric fruit do not produce either a respiratory peak or an ethylene surge during ripening, and there is no autocatalytic ethylene production. Rather they show a steady decline in respiration rate and a low rate of ethylene production as ripening proceeds. They normally are ready to eat at harvest.

Exposure to ethylene, or an analogue of ethylene, stimulates ethylene production, but only as long as the source is present. Thus during storage, ethylene-sensitive products should not be stored with climacteric fruit otherwise premature, unplanned, and uncontrolled ripening can occur.

Methods of Fruits and vegetables Storage:

Low-temperature storage (given cognizance of potential chilling injury in susceptible products) major weapon that the post harvest operator has to maintain quality and extend life of harvested fresh products. Low temperatures:

- reduce respiration rate
- Reduce nutritional loss
- Decreased rate of deterioration
- Increased storage and shelf life
- Reduce water loss through transpiration
- Reduce ethylene production

Differences do exist in temperature effect among cultivars, so it is important that this be taken into account for cool store and packaging.

Packages should be designed to allow cool air to flow directly over products, ensuring rapid temperature pull-down and consequent temperature maintenance. Another factor that affects respiration is the air composition in the store and the boundary layer.

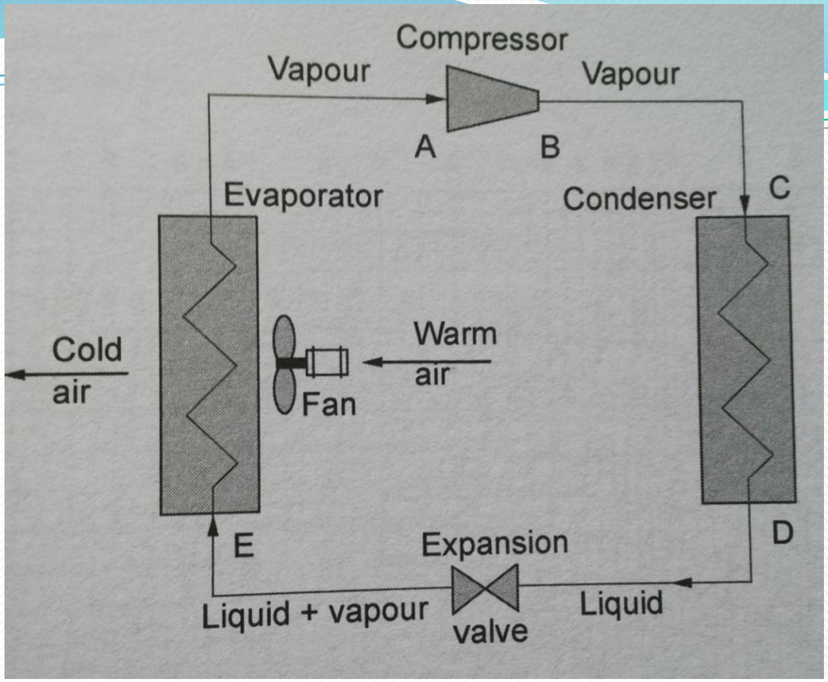
- Low temperature in conjunction with control atmosphere and modified atmosphere storage is been used to extend the shelf life of fruits and vegetables far longer than their natural shelf life.
- However, while using low temperature storage potential of chilling injury to the crop should be taken in to consideration.
- Most tropical and subtropical products are susceptible to chilling injury when exposed to temperatures above freezing but below a critical threshold temperature for each particular product. These chilling temperatures cause breakdown of cellular membranes, resulting in loss of compartmentalization within the cells of the tissue, increased leakiness, water soaking of tissue, and eventually pitting or browning.
- Low temperature for horticultural product storage can be achieved by mechanical chillers, use of evaporative coolers, night ventilation, well water etc.

Mechanical Coolers

Mechanical vapour compression coolers have four basic compartments:

- an evaporator,
- a compressor,
- a condenser and
- an expansion valve.

Cooling takes place as the refrigerant moves between these four compartments changing state from liquid to gas and back to liquid, with changes both in pressure and enthalpy at each stage



Mechanical vapour compression coolers

Refrigerant vapour enters the compressor from the low pressure side of the cycle (A) having pressure P1 and enthalpy H2

it is compressed to a higher pressure P_2. The outlet pressure from the compressor must be high enough to enable condensation of refrigerant by cooling medium at ambient temperature.

- During compression the enthalpy of the refrigerant is increase to H_3 as well as increases its pressure and temperature. The size of the compressor is selected to pump refrigerant through the system at the recommended flow rate and pressure. The operating pressure depends on the type of refrigerant being used and the required evaporator temperature.
- The refrigerant passes to the condenser, where cool air or water flowing through condenser coils absorb heat from the hot refrigerant vapour, causing it to condense back to a liquid state. The enthalpy of the refrigerant falls to H_1 but the pressure remains constant.

- The liquid refrigerant then passes at a controlled rate through the expansion valve at constant enthalpy H_1. The refrigerant pressure falls to P_1 and some of the refrigerant changes to gas.
- The gas liquid mixture passes to the evaporator, where the liquid refrigerant evaporates under reduced pressure and in doing so absorbs latent heat of vaporization and cools the warm air in the cold room.
- The refrigerant evaporates to become a saturated vapour. The enthalpy of the refrigerant increases from H_1 to H_2 but the pressure remains constant.
- The refrigerant then passes to the compressor and the cycle continuous.

- This is an idealised refrigeration cycle and in practice deviation from this cycle includes fluid friction, heat transfer losses and component inefficiency. This prevent the refrigeration cycle from operating at the optimum performance. The coefficient of performance (COP) is the ratio of the heat absorbed by the refrigerant in the evaporator and heat equivalent of energy supplied to the compressor

$$COP = \frac{H_2 - H_1}{H_3 - H_2}$$

where H_1 (kJ/kg) enthalpy of refrigerant leaving the condenser; H_2 (kJ/kg) enthalpy of the refrigerant entering the compressor and H_3 enthalpy of refrigerant leaving the compressor. COP is an important measure of the performance of refrigeration system. Its value is typically between 3 to 6

- The work done on the refrigerant in the compressor can be calculated from the refrigerant flow rate and the increase in enthalpy as $q_w = m(H_3 - H_2)$
- where q_w (kW) is rate of work done on refrigerant; m (kg/s) mass flow rate of refrigerant.
- The rate of heat removal in the condenser q_c (kW) is found as

$$q_c = m(H_3 - H_1)$$

- while the refrigeration effect is the difference in enthalpy between the inlet and outlet to the evaporator
  - $H_2 - H_1$

- To chill fresh foods it is necessary to remove both field heat and heat generated by respiratory activity. The rate of heat removal from a cold store or food is known as the cooling load. The refrigeration flow rate can be calculated from the cooling load on the system and the refrigeration effect as

$$m = \frac{Q}{(H_2 - H_1)}$$

- where *m* (kg/s) refrigeration flow rate *Q* (kW) is the cooling load.
- A vapour compression evaporator has 30 kW cooling load. The evaporator temperature is 5°C and the condenser temperature is 43°C. The compressor efficiency is 80%. Calculate the compressor power requirement and the COP of the system. The values of H_1, H_2, H_3 is 165kJ/kg, 295kJ/kg and 326kJ/kg respectively.

- Mass flow rate of refrigerant m = 30/ (295 – 165) = 0.23 kg/s
- Compressor power requirement (work done in the compressor) =0.23 (326 – 295)/0.8 = 8.95kW
- COP = (295-165)/(326-295) = 4.2

- ***Evaporative Cooling***
- Evaporation of water requires heat. Evaporative-cooling systems extract this heat from the product. Evaporative-cooling techniques could be energy-efficient.
- A well-designed evaporative cooler produces air with a relative humidity greater than 90%.
- Its main limitation is that it cools air only to the wet-bulb temperature of the outside air.
- It is also practical to cool by evaporating water from the commodity. This system prevents heat build-up and keeps the product below the outside air temperature. Using this system for any great length of time may result in excessive water loss.

- ***Night Cooling:*** In places where significant differences between night and day temperatures exist, nighttime ventilation can be a means of cooling. In desert climates the difference between daily maximum and minimum temperatures can be as high as 22°C during the summer. Night cooling is commonly used for unrefrigerated storage of potatoes, onions, sweet potatoes, squashes, and pumpkins. Night ventilation effectively maintains the desired product temperature for 5 to 7 hours per day if kept under shade.

- ***Well Water*** In some areas, well water can be an effective source of cooling. The temperature of the ground more than about 2 m below the surface is lower than the atmospheric temperature by up to 5°C. This advantage can be used to cool harvested crops.

- **Controlled and Modified Atmospheres Storage**
- It has long been recognised that controlling the atmosphere around products influences respiration rate.
- Respiration rate is a function of O_2 and CO_2 concentration. Respiration decreases as O_2 concentration decrease in the environment.
- In CA rooms the oxygen content is reduced and the carbon dioxide content is increased to a predetermined level, according to the requirement of the various products.
- With this system fruits can be stored for more than a year and look and taste like freshly picked products.
- The changed air composition in the stores keeps the product in a dormant state, with the respiration and other life processes slowed down thus decreasing deterioration.
- In order to obtain the best result in storage it is advised to pick, pack and store the fruits on the same day.

Chambers of 50 – 250 tonnes capacity have been found most economical and suitable for storage of fruits. Temperatures are controlled using sensing elements located in various spots. Variation in temperature within the store should not be more than ± 0.5°C

The following conditions must be in place for operations of CA rooms:

- Gas tightness
- Means of removal of excess CO_2 from the atmosphere
- Means of ventilation for even atmospheric condition within the store
- Means of providing suitable relative humidity and temperature
- Means of adjustment of atmospheric pressure
- Means of supply of air in emergency cases
- And means of controlling all the parameters (gas composition, temperature, relative humidity, atmospheric pressure etc..)

- **Modified atmosphere** storage is the practice of modifying the composition of the internal atmosphere of a package (food packages) in order to improve the shelf life of the product. The modification process often tries to lower the amount of oxygen (O_2), moving it from 20.9% to 3%, in order to slow down the growth of aerobic organisms and the speed of oxidation reactions. The removed oxygen can be replaced with nitrogen (N_2), commonly acknowledged as an inert gas, or carbon dioxide (CO_2), which can lower the pH or inhibit the growth of bacteria.
- In MAP the atmosphere is passively regulated depending on product nature, mass & temperature, and nature of a polymeric film used. Modifying of gases inside the packaging can be achieved using active techniques such as gas flushing and vacuum or passively by product respiration or use of "breathable" films known as equilibrium modified atmosphere packaging (EMAP).

- Packets containing scrubbers may also be used.
- It is also crucial that temperatures of modified-atmosphere packages are prevented from rising too high A major problem with modified-atmosphere generation in polymeric films arises from the fact that the increase in product respiration rate with temperature is greater than the increase in film permeability to respiratory gases over the same temperature range.
- This results in elevated CO_2 and depressed O_2 concentrations inside packs that may exceed the physiological thresholds for damage, leading to development of off-flavour.

- Some limitation of MAS and CAS are:
- The low level of O_2, or high levels of CO_2, which are needed to inhibit bacteria or fungi could be harmful to some foods.
- CAS may lead to an increase in the concentration of ethylene in the atmosphere and accelerate ripening and the formation of physiological defects.
- An incorrect gas composition may change the biochemical activity of tissues, leading to development of off odours, off flavours, a reduction in characteristics flavours or anaerobic respiration.
- Tolerance to low O_2 and high CO_2 concentration varies according to type of crop, condition under which a crop is grown and maturity at harvest. Thus cannot be stored together.
- Cultivars of the same species respond differently to a given gas composition, thus require separate stores.
- MAS and CAS must be in combination with cold storage.
- High cost of the entire system.

FOOD PACKANG:

Food Packaging is an integral part of food processing and storage. It performs two functions:

- To hold the food and protect it to predetermine degree for the expected shelf life
- To advert food at the point of sale.

Additional requirement of food package are:

- The package should not influence the product (for example by migration of toxic compounds, by reaction between the pack and the food or by selection of harmful microorganisms in the packaged foods).
- It should enable smooth, efficient and economical operation on the production line, during storage and distribution, including easy opening, dispensing and resealing and being suitable for easy disposal recycling or reuse.
- Should have resistance to breakage (for example fractures, tears or dents caused by filling and closing equipment, loading/unloading or transportation) and
- Should have total minimum cost.

Factors That Cause Deterioration of Foods

Main factors that cause deterioration of foods during handling and storage and which should be protected are:

- Climatic influences that cause physical or chemical changes such as UV light, moisture vapour, oxygen, other gasses and temperature changes.
- Contamination by microorganisms, insects or soils
- Mechanical forces such as impact, vibration, compression or abrasion and
- Pilferage, tempering and adulteration

- **Light**: light transmission is required in packages that are intended to display the contents but is restricted when foods are susceptible to deterioration by light (for example oxidation of lipids, destructions of riboflavin and losses of colour). The amount of light absorbed by food is found using the following equation: $I_a = I_i T_P \frac{1-R_t}{1-R_t R_P}$
- Where *Ia* (Cd) is the intensity of light absorbed by the food, I_i (Cd) is the intensity of incident light, T_p the fractional transmission by packaging material, R_P the fraction reflected by packaging material and R_t the fraction reflected by the food.
- The intensity of light transmitted by the packaging material is found using the beer-Lambert law as $I_t = I_i e^{-kx}$
- where I_t (Cd) is the intensity of light transmitted by packaging, k the characteristic absorbance of packaging material and x (m) the thickness of packaging material.

- The amount of light that is absorbed or transmitted varies with the packaging material and with the wavelength of incidence light.
- Some materials (for example low density polyethylene) transmit both visible and ultraviolet light to a similar extent whereas others (polyvinylidene chloride) transmit visible light but absorb ultraviolet light.
- Pigments are incorporates into glass containers or polymer films, or they are printed to reduce light transmission to sensitive products.

- **Heat / Temperature**: The insulating effect of a package is determined by its thermal conductivity and its reflectivity.
- Materials which have low thermal conductivity (paperboard, polystyrene or polyurethane) reduce conductive heat transfer, and reflective materials (aluminium foil) reflect radiant heat.
- The amount of conductive heat transmitted can be calculated as

$$Q = \frac{kA(t_1 - t_2)}{x}$$

- **Moisture and gasses:** The rates of moisture and oxygen transfer are the main factors that control the shelf life of dehydrated foods and those that contain appreciable quantities of lipids or other oxygen-sensitive components.
- Transfer of moisture, oxygen and carbon dioxide through packaging materials is critically important in determining the shelf life and quality of chilled fresh foods and of foods packaged in modified atmosphere.
- The concentration of oxygen has effect on the nutritional and sensory qualities of foods
- also water activity has an effect on shelf life of stored foods.

- Assuming that a packaging material has no defect and that there is no interaction between the film and the gas or vapour, the mass transfer rate m of gas or vapour through a packaging material is found using the following relationship: $m = \frac{bAt\Delta P}{x}$
- where *b* (m^2) is the permeability of the material, *A* (m^2) the area of material, *t*(h) the time, *ΔP* (Pa) the difference in pressure or concentration between the two sides of the material and x (m) the thickness of the material.
- Permeability is related to both the film and the gas or vapour and is not therefore a property of the film alone.

- Permeability of materials changes with humidity variation, owning to interaction of water with the material.
- The film thickness, chemical composition, structure and orientation of molecules in a packaging material influence the barrier properties.
- Permeability is also related exponentially to temperature and it is therefore necessary to quote both the temperature and relative humidity of the atmosphere in which permeability measurements are made.

Microorganism: Intact packaging materials are barrier to microorganism, but seals are a potential source of contamination. Differences in permeability of packaging material have an effect on the growth of micro organism in foods.

The main causes of microbial contamination of adequately processed foods are:

- Contaminated air or water drawn through pin holes in hermetically sealed containers as the head space vacuum forms.
- Contamination of heat seals by product
- Poorly aligned lids or caps and
- Damage to the packaging material (tears, creases)

- **Mechanical Strength:** The ability of packages to protect foods from mechanical damage is measured by, the tensile strength, Young's modulus, the tensile elongation, the yield strength and the impact strength.
- Each of the factors is influenced by the temperature of the material and the length of time that the force is applied.
- The molecular structure of polymer films is aligned in different ways depending on the type of film and method of manufacture.
- Each of these properties is therefore measured in both the axial direction and lateral direction or both directions (biaxial). Orientation of the molecules in these directions improves the mechanical properties of some films.

- **The Main Marketing Considerations While Advertising Foods Are:**
- Identify the content and assist in selling the product
- Advertising the brand image and style of presentation required for the food
- Flexibility to change the size and design of the containers and
- Compatibility with the method of handling distribution and the requirement of the retailer.
- In addition to this the package should be aesthetically pleasing, have a functional size and shape, retain the food in a convenient form, possibly act as a dispenser and be suitable for easy disposal or reuse.
- The package design should also meet any legislative requirements concerning labelling of foods.

- **Types of Packaging Materials:**

- There are two main groups of packaging materials:
- **Shipping** containers which contain and protect the contents during transport and distribution these include wooden, metal or fibreboard cases, crates, barrels, drums and sacks
- **Retail** containers or consumer units which protect and advertise the food in convenient quantities for retail sale and home storage example are metal cans, glass bottles, jars, rigid and semi-rigid plastic tubes collapsible tubes paperboard cartons, and flexible plastic bags sachets and over wraps.

- Packages and packaging are made of various materials. These include:
- **Textile and Woods**: these are mainly used as shipping containers it consist of woven jute sacks, textile sacks, wooden creates and wooden containers.
- Wood offers good mechanical protection, good stacking characteristics and high weight to strength ratio. Wooden containers for wine and spirit are used because of the transfer of flavour compounds from the wooden barrels which improve the quality of the product.
- Wooden containers are however very expensive and are being replaced by polypropylene and polyethylene containers.
- Wooden containers are also heavy which increase transporting cost of the product.
- Textile sacks have poor gas and moisture barrier properties and they are not suited to high speed filling and have poorer appearance.
- Woven jute sacks which are chemically treated have high tear resistance low extensibility and good durability. They are used to transport bulk foods including grains, flour, sugar and salt.

- Metal: metal cans have a number of advantages over other types of containers. Some of the advantages are:
- they provide total protection of the content,
- they are convenient for ambient storage and preservation and they are tamperproof.
- However high cost of metal and high cost of manufacturing makes cans expensive.
- They are also heavier than other material therefore incur high transport cost.
- Metal containers are divided in to three piece can, two piece can, aluminium foil and aerosol cans.
- Three piece cans consists of the can body and two end pieces. They are used to seal heat sterilized foods hermetically and also for powders, syrups, and cooking oil.

- Generally they are made from steel which coated on both sides with thin layer of tin.
- Two piece aluminium cans are made by draw and redraw (DRD) or draw and wall iron (DWI) processes. They consist of two parts, the body and the top cover of the can.
- Two piece cans are used for carbonated drinks and heat sterilized foods. Aluminium foils is produced by cold reduction process in which pure aluminium is passed through rollers to reduce the thickness to less than 0.152mm and annealed to give dead folding property.
- The advantages of foil include a good appearance, dead folding, the ability to reflect radiant energy and an excellent barrier to moisture and gases. It is widely used for wraps, bottle caps and trays for frozen and ready meal. It is also used as a barrier material in laminated films and to metalize flexible films.

- Glass: Glass containers have a number of advantages:
- They are impervious to moisture, gases, odours and microorganisms;
- they are inert and do not react or migrate into food products;
- they have filling speeds comparable with those of cans;
- they are suitable for heat processing when hermetically sealed;
- they are reusable and recyclable; reseal able; transparent to display the content;
- they can be moulded into variety of shapes and colours;
- they are rigid and allow stacking;
- they are perceived by customers to add value to the product
- However glass also have disadvantages such as higher weight which incurs transportation costs;
- have lower resistance than other materials to fracture, scratches and thermal shock;
- potentially serious hazard from glass sprinters or fragments in food.
- A wide range of things are packaged in glass containers beverages; dried products; high moisture products, vegetable oils etc

- Paper and board: Paper pulp is produced from wood chips by acid or alkaline hydrolysis.
- Verities of paper products are available for packaging food items. Kraft paper is a strong paper which is used for 25 to 50kg multi wall sacks for powders, sugar fruits and vegetables,
- lighter papers are used for grocery bags and sweet wrappers, as an inner liner for biscuits.
- Cartons and boards are thicker and are able to protect foods from mechanical damage.
- Paper and boards provide a good barrier to gasses they are easy to print
- However, they do not provide protection against moisture and oil or fat.
- They are used for wide range of products. They are combined with aluminium foil or polyethylene films to increase its protection ability. Polyethylene and paper are combined for packaging aseptically sterilized foods.

- Flexible films. Flexible packaging describes any type of material that is not rigid and is made of non fibrous material.
- A large number of flexible films are available and have the following properties:
- they cost is relatively low,
- have good barrier properties against moisture and gasses,
- they are heat sealable to prevent leakage of contents,
- they are suitable for high speed filling, they have wet and dry strength, they are suitable for printing,
- they are easy to handle and convenient for the manufacturer retailer and consumer, they add little weight to the product,
- they fit closely to the shape of the food thereby wasting little space during storage and distribution and they are formed in different form, shape and colour.

- Rigid and semi rigid containers: these are containers made from single or coextruded polymers. They have the following advantages:
- Lower weight compared glass or metal containers
- Lower production temperatures, lower energy cost
- Can be moulded into a wide range of shapes
- Can be easily coloured

Its disadvantage include

- They are not reusable, has lower heat resistant and are less rigid than glass and metal

- LANDMARK UNIVERSITY, OMU-ARAN, NIGERIA

Department of Agric and Biosystems Engineering

2015/2016 MID-OMEGA SEMESTER EXAMINATION

ABE 523: Food and Crop Storage Engineering

- Q1. List and discuss environmental factors that affect respiratory activities of stored perishable and semi perishable crops
- Q2. Give the simplified representation of respiratory activity
- Q3. List and discuss methods of deoxygination of stored grains
- Q4. What is the effect of transpiration in stored tubers? give the mathematical relationship that define transpiration
- Q5. Discuss the different methods of loss estimation in stored grains
- Q6. What are cautions to be taken when using hermetic stores for grain storage?

Quiz 1

- Q1. List and discuss environmental factors that affect respiratory activities of stored perishable and semi perishable crops
- Q2. Give the simplified mathematical representation of respiratory activity
- Q3. What is the effect of transpiration in stored tubers?
- Q4. List the similarities and differences in Control Atmosphere and Modified Atmosphere storage

Assignment: The Role of Appropriate Methods of Packaging and Storage of Agricultural Products in Achieving Food Security

- minimum of three and maximum of five pages excluding cover page and references
- Font Times New Roman, size 12, 1.5 spacing
- Margins 2 cm top, bottom, left and right
- Submission hard copy to class rep on 30 May, 2016
- Soft copy same day to osunde.zinash@lmu.edu.ng

Quiz

ABE 523 Food and Crop Storage Engineering

1. List at least two disadvantages and four advantages of modern storage methods
2. Why is storage a very important aspect of farm business?
3. Describe any of the traditional storage structure used in the Sudan Savanna

- Disadvantage: high cost; need technical now how; need etra handling operations;
- They are rat and moisture proof there is no damage due to termites
- They are adequately airtight
- They have efficient method of loading and off loading
- The grains can be stored in threshed condition rather than un-threshed and thereby increase the storage capacity
- There is adequate protection against fire and theft
- The storage losses are comparatively less
- The lifespan of these storage structures are long and annual maintenance cost is low
- Although the initial cost of construction is high annual cost of storage is comparatively less

- The density of gas depends on their pressure and temperature. Pressure is often expressed as gauge pressure when it is above atmospheric pressure. Pressure is calculated using the ideal gas equation as follows: $PV=nRT$
- From slide 169

- where P (P_a) absolute pressure, V (m^3) volume, n (kmol) is number of moles of gas, R is the gas constant (8314,4 J/kmol K) and T (K) = temperature. This equation is useful for calculation of gas transfer in MAS or MA packaging applications.
- Calculate the amount of oxygen (kmol) that enters through a polyethylene packaging material in 24h at 23°C, if the pack has a surface area of750cm² and an oxygen permeability of 120 ml/m² per 24h at 23°C and 85% relative humidity. Atmospheric pressure = 10^5 Pa.
- $$V = 120\ x\ \frac{750}{100^2} = 9\ cm^3$$
- using the gas equation ($PV=nRT$) 10^5 x 9.0 = n (8314.4 x 296)
- n = 10^5 x 9.0 x 10^{-6} / (8314.4 x 296) = 3.66 x 10^{-7} kmol