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| COURSE CODE: | <i>AGE 512</i> |
| COURSE TITLE: | <i>Food and Crop Storage Technology</i> |
| NUMBER OF UNITS: | <i>3 Units</i> |
| COURSE DURATION: | <i>Three hours per week</i> |

COURSE DETAILS:

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| Course Coordinator: | Prof. Adewumi, Babatunde Adewale B.Sc., M.Sc. Ph.D |
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| Other Lecturers: | None |

COURSE CONTENT:

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

COURSE REQUIREMENTS:

Course to be taken by final year students of Agricultural Engineering Department, especially those in storage and processing option. 75% attendance must be satisfied by students.

READING LIST:

1. Adewumi, B.A and A.F Akerele. 2003. Evaluation of the storage qualities of onions in domestic environment. Proceeding of the Nigeria Society of Bio Technology, 25:103-106.
2. Adewumi, B. A., J.C Igbeka and A.A Satimehin. 1990. Evaluation of crib storage structures in South Western Nigeria. Paper presentation at the Annual Conference of the Nigerian Society of Agricultural Engineers, Makurdi.
3. Adewumi, B.A and O.S.V Oduwale. 1995. Problems affecting the utilization of silo storage in Nigeria” NSE Technical Transactions 3 (2): 27-32.

4. Adesida, M.A. 1889. Economics of grain storage in the warehouses in Nigeria. Post Harvest News, 3:2-5, 2001.
5. Agboola, S.D. 1983. Information Booklet. Publication of the Nigerian Stored Products Research Institute (NSPRI), Lagos Nigeria.
6. Ajibola, O.O. 1994. Desorption isotherms for plantain at several temperatures. Journal of Food Science 51:69-71.
7. Ajisegiri, A.S. 1989. Sorption phenomena and storage stability. Ph.D Thesis (unpublished), University of Ibadan, Ibadan
8. Ajisegiri, A.S. 1990. Improving local rhombus for grain storage. Paper presentation at the Conference of the Nigeria society of Agricultural Engineers, Makurdi.
9. Babarinsa, F.A. 2001. Grain storage in silos without insecticides. Post Harvest News 3:1-5.
10. Brummer, H. 1989. Grain cooling in steel silo. World Farming 8:30-35, 1983
11. Cruz, J.P. and A. Diop. Agricultural Engineering in development: Warehouse technique.
12. Faseyi, O.W. 2001. Report on the training organized by the Chinese Government on grain storage management and technology. Federal Ministry of Agriculture, Nigeria. 20pp.
13. Henderson, S. M. and Perry, R. C. 1976. Agricultural Process Engineering. 3rd Edition. Avi Textbook Series.
14. Igbeka, J.C. 1991. Indigenous and modern methods of grain preservation and storage. An invited paper presented at the NSE course on design, construction and maintenance of food storage system.
15. Labuza, T.P. 1968. Sorption phenomena in food. Food Technology 22 (3): 15 – 24.
16. Minjinyawa, Y. 2010. Farm structures. 2nd Edition. Ibadan University Press, Ibadan, Nigeria.
17. Mohsenin, N. 1970. Physical Properties of Plant and Animal Materials. Vol.1. 1st Ed. Gordon and Breach Science Publisher.
18. NAS. 1998. Post harvest losses in the developing countries Publication of the National Academy of Science, Washington, D.C, U.S.
19. Okunola, A.A 1995. Equilibrium moisture content and relative humidity of source tropical root crops. Proceeding of the Agricultural Society of Nigeria Okunola, A.A. and J.C Igbeka. 2000. Water absorption characteristics of plantain and sweet potato. Proceeding of the Nigeria Institution of Agricultural Engineers, 22:20-25.
20. Rudenko. Material Handling Equipment. Peace Publisher, Moscow.
21. Sinha, R.N &Muir. Grain Storage: Part of a System. Avi Publisher.
22. Sinha, R.N 1971. Interrelations of physical, chemical and biological variables in deterioration of stored grains. In: Grain storage Part of the system.

Note: This is a sketch note. Detailed information including relevant figures, charts, tables and equations shall be made available during classes.

LECTURE NOTES

Food and Crop Storage Technology

1.0 BASIC DEFINITION AND INTRODUCTION

1.1 Basic Definitions

What is Storage and why storage?

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

Storage is essential for the following reasons:

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

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

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

periods is between 72 – 84% while the environmental temperature is between 26-30°C. These climate conditions are not adequate for the traditional method of storage practiced by most farmers.

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

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

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

2.0 CLASSIFICATIONS OF THE TYPES STORAGE

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

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

2.1 Classification Based on Duration of Storage

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

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

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

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

2.2 Classification Based on Scale of Storage

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

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

Small scale storage systems have capacity for up to 1 ton, but not beyond. They are mostly used at domestic and peasant levels. They are associated with peasant farmers with small farm holdings. Medium scale storage can accommodate up to a hundred tons of stored products. Most of such storage systems are in the capacity range of 2 – 50 tons, with very few having capacity beyond 50 tons. Some are used in breweries for temporary storage of spent grains. Large scale storage can accommodate stored material in 100s and 1000s of tons. It is used either for temporary or permanent storage of very large quantity of various products. It has a very high initial cost but eventually reduces overall unit cost of production.

2.3 Classification Based on Principle of Operation of the Storage System

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

- Physical Storage
- Chemical Storage
- Biological Storage

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

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

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

3.0 FACTORS AFFECTING CROP STORAGE

Storage deterioration is any form of loss in quantity and quality of bio-materials. The major causes of deterioration in stored could be physical, chemical & biological in nature. These factors include:

- Micro organisms
- Insects and mite
- Birds, pests rodents
- Metabolic activities
- Environmental factors

It is advisable to start storage with quality food product. Storage only preserves quality. It never improves quality. Product with initial poor quality quickly depreciates.

3.1 Micro organisms

Major micro organisms associated with storage include fungi, bacterial and yeast. The activities of micro organism result in color degradation, off flavor, moisture upgrading, wet spot & moldiness, loss of viability, etc

Fungi are parasite to stored products. They deteriorate stored products and also cause diseases to consumers. The class of fungi mostly important in crop storage is mould. They cause hot spot and increase the moisture content of stored product. When uncontrolled, deterioration is rapid resulting in loss in viability of seed, off-flavour which renders the grain unfit for milling and malting. They also produce mycotoxins which are toxic both to man and animal. They cause discolorations, moistness, biochemical changes and loss in weight. Fungi and bacteria prefer acidic concentration for growth. At high temperature (20%) yeast could ferment soluble carbohydrate to form alcohol and organic acid.

3.2 Insects and Mites

Generally, insects have short life span but since they reproduce in storage, they continuously increase in number. Weevils are the commonest grain insects. Insects and mites attack both the crop and the storage structure. Female insects bore the seeds and lay eggs in the seeds. Insects consume the stored product; contaminate them with fragments and faeces. They reduce crop

weight, quality, nutritional value and viability. They introduce ill-smell to product. Insect could cause the temperature of stored product to increase up to 42°C (108F). This can lead to hot spot.

Grain infesting insects are usually inactive when the moisture and temperature are not above 9% and 40F respectively. Sources of insect infestation include residues from the previous year(s); the infested store; crops can be infested from the field; rodents are also insect carriers. Control measures against insect infestation include chemical control; cleaning of grains; adequate drying; and gas sealed storage. Correct dosage of chemicals must be used to avoid contamination. Old stock grains should not be mixed with new stock. The storage facility and the immediate environment should be disinfested with insecticide.

Insects, mites and pests attack both the stored material and wooden components of the storage structure. Weevils are the commonest insects in grains. They attack seeds and bore through them, and lay eggs in the seeds and storage structures. They reduce seed weight, quality, nutritional value and viability.

3.3 Birds, Pest and Rodents

Birds feed on grains especially when shelled. Birds mostly infest grains on the field where they are exposed. Birds only cause a loss in weight (quantity) and do not seriously affect the quality of grains.

Rodents are animals (mostly mammals) that parasite crops. In attempt to get to the stored product they can destroy buildings, storage structures and some other valuable materials on the farm. Rodents eat the germ of grains and waste the remaining parts. Rodents are vectors (disease carrier) in most cases. They contaminate stored crops with their faeces. Some rodents die in the store and decays hence initiating the rapid growth of micro-organism. The existence of rats can be identified by droppings; loose earth from burrowing; foot print and dusty floor holed sacks with grains, droppings and gnawing damage to woven fabric.

Control measures for rodent that have been practiced include keeping cats and dogs near the store; environmental sanitation; use of rodent proofing such as guard; elevating the storage floor (at least 50cm for concrete floor and 75cm for metal or wooden floor; use of traps and chemical

control. It is advisable not to place bicycle or any object which rat can climb against the storage structure.

3.4 Metabolic Activities

Respiration is a major metabolic activity that occurs in stored grains, and storage organisms (insect, micro-organisms and rodent) living on or in the stored grains respire. Heat, water and carbon-di-oxide are released during respiration. The heat thus generated is capable of increasing the temperature of the stored product leading to a hot spot. Hot spot damages the embryo and reduces viability of crop. A temperature of 15°C is therefore, recommended for stored product at 13 – 14% moisture content.

3.5 Environmental Factors

The environmental factors that mostly associated with stored products include:

- Temperature
- Relative humidity
- Equilibrium moisture content
- Pollution by chemicals and smoke

Moisture content, relative humidity and storage temperature are three major parameters that must be monitored and controlled during storage to ensure a safe storage otherwise storage losses would be excessive. Moisture content is the amount of water molecule contained in an agricultural material. It could be defined on wet basis (M.C_{wb}) or dry basis (M.C_{db}). It is expressed either as ratio or percentage.

$$M.C_{wb} = \frac{\text{weight of water}}{\text{weight of wet product}} \dots\dots\dots(1)$$

$$M.C_{db} = \frac{\text{weight of water}}{\text{weight of dry product}} \dots\dots\dots(2)$$

M.C_{wb} is used for commercial purpose while M.C_{db} is used for scientific purpose. The relationship between M.C_{wb} and M.C_{db} is given below:

$$M.C_{db} = \frac{M.C_{wb}}{1 - M.C_{wb}} \dots\dots\dots(3)$$

$$M.C_{wb} = \frac{M.C_{db}}{1 + M.C_{db}} \dots\dots\dots(4)$$

In storage, we are more concerned with the equilibrium moisture content. This is because the stored product interacts with its immediate environment since agricultural material is hygroscopic. When products are kept in an environment, there is a continuous interaction of moisture between the product and the environment. At a point the product attains equilibrium with the environment and the moisture interaction ceases. This is called the Equilibrium Moisture Content (EMC). Table 1 shows the EMC of cereal for safe storage.

The EMC of any stored product is affected by climatic factors such as rainfall, relative humidity and temperature. Regions with high RH tend to keep stored crop at a high EMC and this is not safe for storage. Table 2 shows the EMC of various seed at various RH.

Table 1: EMC of Cereals for Safe Storage (wet basis)

| Cereal | E. M. C. for safe storage | |
|---------|---------------------------|-------------|
| | For 1 year | For 5 years |
| Barley | 13 | 11 |
| Maize | 13 | 10 – 11 |
| Oat | 13 | 11 |
| Rice | 12 – 14 | 10 – 12 |
| Rye | 13 | 11 |
| Sorghum | 12 – 13 | 10 – 11 |
| Wheat | 13 - 14 | 11 - 12 |

Source: Brooker et. Al., 1974.

Table 2: EMC of Various Seeds at Various Air RH

| Seed | Air Relative Humidity | | | | | | |
|-------|-----------------------|------|------|------|------|------|------|
| | 40 | 50 | 60 | 70 | 75 | 80 | 90 |
| Wheat | 10.7 | 12.0 | 13.7 | 15.5 | 16.6 | 17.6 | 23.0 |
| Maize | 11.0 | 12.0 | 13.0 | 15.0 | 15.5 | 16.0 | 20.0 |
| Rye | 10.0 | 11.6 | 13.2 | 14.8 | 16.1 | 17.3 | 24.6 |
| Pea | 9.4 | 11.1 | 13.1 | 15.5 | 17.2 | 19.5 | 27.7 |
| Bean | 9.1 | 11.1 | 13.1 | 15.8 | 18.0 | 20.4 | 28.0 |
| Grass | 8.9 | 10.3 | 11.6 | 13.9 | 15.4 | 17.1 | 23.3 |
| Onion | 8.3 | 9.6 | 10.8 | 12.6 | 14.1 | 16.2 | 23.5 |

Source: ASAE Yearbook

It is worth noting that chemicals, dust and smoke generated from the environment of storage structures can contaminate stored products either by discoloration and occasionally can be poisonous.

4.0 MOISTURE MIGRATION AND ISOTHERM IN BIO-MATERIALS

The concepts of moisture migration and moisture isotherm are very essential in bio-material handling because they affect the behavior, storage and drying of bio-materials. Moisture can migrate both within and on the surface of bio-material in response to the fluctuations in relative humidity and temperature. The interaction between EMC, relative humidity and temperature is known as moisture isotherm.

Henderson equation shows the relationship between the EMC, Temperature and RH as stated below:

$$1 - a = e^{-kT(Me)^n} \dots\dots\dots(5)$$

$$\ln(1-a) = -kT(Me)^n \dots\dots\dots(6)$$

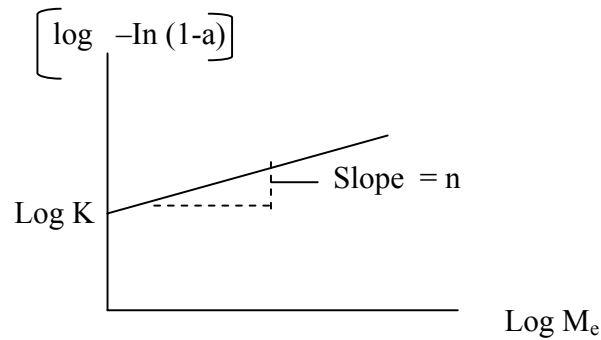
$$\log[-\ln(1-a)] = n \log Me + \log K \dots\dots\dots(7)$$

If temperature is constant, $K = kT \dots\dots\dots(8)$

- Where, Me = EMC in decimal
- a = RH or water activity in decimal
- T = absolute temperature

k & n are constant depending on product characteristics.

The values of K (kT) and n are obtained by plotting a graph of $\log(-\ln(1-a))$ vs $\log Me$. The slope of the graph gives the value of n and the intercept gives the value of $\log K$. To obtain K find the antilog of the intercept.



Where,

$$n = \frac{\Delta \log [-\ln (1-a)]}{\log M_e}$$

Henderson equation is graphically represented on the isotherm curve. This curve is sigmoidal (See Fig 1). On the isotherm plot, we could either draw the sorption curve or the desorption curve (See Fig. 2). The sorption curve shows the isotherm plot for product absorbing moisture while desorption curve shows the isotherm plot when water is withdrawn (during drying) from product. It should be noted that the two curves do not follow the same path, but both have sigmoidal shape. The desorption curve is always above the sorption curve. There is hysteresis between the two phenomena. This is because more energy is required to withdraw moisture from stored grains.

Further research showed that the moisture isotherm is not a perfect sigmoid. Rockland, 1957, discovered that a typical isotherm is made up of series of straight line. And, he identified 3-basis “local isotherms” (See Fig. 3). Each local isotherm corresponds to the degree of wetness of the product. He therefore, partition the isotherm into three local isotherm (or water binding layer) namely:

1. Monolayer water binding: This is a very dry region.
2. Multi-molecular binding: This is the most stable region.
3. Kelvin Moisture layer or Saturation layer: This is the most unstable layer.

Deterioration is very high in the saturation layer (3). For safe storage, we select storage conditions using the stable local isotherm (2). It should be noted that each of the local isotherms has its own values of k & n.

Higher environmental temperature assists or accelerates crop drying in crib storage. However, higher environmental temperature poses a lot of problems to enclosed (bin) storage structures. This is the major disadvantage to silo storage in the tropics. High temperatures and temperature variations lead to moisture migration and moisture condensation in silo. Moisture build is always noticed at the middle region of silo. This eventually results in micro-organism infestation and spoilage. This soon spread throughout the silo.

The maximum storage life of corn (T) was related to moisture content, temperature and mechanical damage using the relationship:

$$T = T_R \times M_T \times M_m \times M_D \text{ (hr)} \dots\dots\dots(9)$$

Where,

T = estimated maximum storage time for a loss of 0.5% dry matter

T_R = time for corn having 25% moisture content (w.b) and 30% mechanical damage, stored at 15.6°C (60F) to lose 0.5% dry matter (T_R = 230hr).

M_T = Temperature multiplier (see Fig. 4)

M_m = Moisture multiplier (see Fig. 5)

M_D = Mechanical damage multiplier (see Fig. 6)

If the required storage period is known, the equation could be used to estimate the storage conditions needed; or, if the storage conditions are known, the maximum storage period can be estimated.

5.0 STORAGE STRUCTURES

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

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

5.1 Traditional Storage Structures

These are devices used mostly for short term and small scale storage. Occasionally they include some medium term and medium scale storage devices. They require low level of scientific knowledge to construct, operate and maintain. They are mostly made of unrefined local materials. Traditional storage structures include:

- Domestic structures
- Rhombus
- Traditional Crib
- Barn
- Shelf
- Pit/ Underground Storage, etc.

5.1.1 Domestic structures

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

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

5.1.2 Rhombus & Traditional Crib

These are used for grain storage, mostly materials in cob. Rhombus is mostly used in Northern Nigeria while the traditional crib is used in South Western and Eastern Nigeria. Rhombus is cylindrical in shape while crib has rectangular shape. They are made of palm font leaf, clay, tree stem and bamboo. Major disadvantages are moisture build as a result of rain, and micro organism infestation. Sometimes coal or wood heat is introduced at the lower base to ensure

drying. They are mostly made of local materials such as palm frond, raffia leaf, bamboo, clay, straw and grass. Grains stored in traditional storage structures are not properly protected from rain. Micro-organism infestation is common in the traditional storage. Drying rate is also retarded in the traditional storage.

5.1.3 Barn, Shelf and Pit

These are mostly used for root and tuber crops. Barn and shelf could be suitable for onion & carrot. Barn, shelf and pit are recommended for cassava, yam and cocoyam. They are affected by environmental conditions.

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

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

5.2 Modern Storage Structures

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

These include:

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

5.2.1 Improved Crib

Improved crib storage has recently gained research interest because of its potentials. The traditional crib storage has been improved. We have the conventional crib storage made of improved material such as sawn wood, iron, wire mesh, galvanized sheet, plastic roof and treated bamboo. The conventional crib has adequate aeration, retarded mould growth and insect infestation and the roof considerably protects stored crop from direct rainfall. Conventional cribs have increased capacity and could store up to 15 tons of cob maize. It is therefore, used for medium scale storage. The long side of the crib should face the windward direction for proper aeration. However, the performance of the conventional crib is not optimal during the raining season. This is because it is exposed and the performance is affected by the climatic conditions. Improved crib structure is an improvement over the traditional crib in terms of design, capacity, construction material and performance. It has upgraded the traditional crib to medium scale storage. Each unit can accommodate 10-20 tons

An improvement over the conventional crib storage is the 'In-bin' crib. The storage chamber of the In-bin crib is not directly exposed. It is enclosed in a metal bin. This crib utilizes a suction fan to ensure adequate air circulation. This crib is known to prevent product from being contaminated with dust and particulate material. Moisture build is also reduced during the raining season. This crib is however still experimental. However, it has not being commercialized.

5.2.2 Warehouse

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

Bagged products are normally stored in the warehouse. Occasionally, bulk materials are also stored in the warehouse. Modern warehouse are provided with material handling equipment especially when bulk materials are stored. Leaking roofs and cracked walls must not be allowed in warehouse. Bagged product are properly stacked on wooden platforms. Effective spacing

requirement for warehouse storage is 1.7m^3 for one ton of grains. However, some allowances should be provided for stacks (platforms) and ventilation. Some warehouses are provided with aerators. The floor of warehouse must be well above the ground level to prevent flooding and a solid foundation must be provided. Water proof materials could be constituents of the foundation. This is to prevent water seepage. The floor should be provided with a proper drainage.

5.2.3 Silo/ Bin

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

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

5.2.3.1 Factors Considered in Silo Design

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

- i. System capacity
 - ii. Location and orientation of bin
 - iii. Handling method and equipments
 - iv. Structural requirements
- (i) System Capacity: It is necessary to know the tonnage or capacity of the system. It is therefore, required to know the quantity of grain to be stored and the number

of bins to be used. The farmer should decide either to have a single bin with a large capacity or have several small bins. In most cases the advantages of using smaller bins override the use of single bin. Grains can be changed from one bin to the other to prevent caking and deterioration. The use of smaller bins provides flexibility and future adaptations.

(ii) Location and Orientation of Bin

This has a major influence on the efficiency of the system. The location will depend on the end use of the stored grains. Location of bin should be done such that excessive handling is minimized. Bins should be installed or constructed on solid foundations. The site must be accessible even during the rainy periods. There must be adequate supply of power. Storage bin should be sited at about 60m away from residence because of the noise produced by the dryer and handling equipment. Orientation of the bin in relation to wind and storm must be proper. Bin should be located on a well drained land to avoid flooding. Otherwise, the bin should be located on elevated foundation.

(iii) Handling Method & Equipment

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

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

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

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

$$P = \int_0^h L dh \dots\dots\dots (1)$$

$$F_v = \mu' P = \mu' \int_0^h L dh \dots\dots\dots (2)$$

$$L = (wR/\mu') (1 - e^{-k\mu'h/R}) \dots\dots\dots (3)$$

Where, for a consistent system of units

- L = Lateral pressure
- w = Grain specific weight
- μ' = Coeff of friction b/w grain and bin wall
- R = area of bin floor divided by the perimeter
- k = ratio of lateral o vertical pressure in grain
- h = Depth of grain to point under consideration
- F_v = Vertical wall load per unit perimeter
- P = Total lateral wall load per unit perimeter

Janssen assumed that k was constant throughout the grain mass in the bin under consideration. Also, for deep bins, the vertical pressure (v) on the floor is determined by the ratio of L & k. Thus, if L is determined for a maximum depth, h, the floor land, V, per unit area is given by

$$V = \frac{L}{k} \dots\dots\dots (4)$$

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

where Θ is the angle of internal friction. Mostly

$$0.3 \leq k \leq 0.6$$

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

Rankine's equation for shallow bins:

$$L = whk \dots\dots\dots (6)$$

The terms are as defined in (3)

Airy's equation for shallow bins:

$$L = \frac{wh}{\left[\sqrt{\mu(\mu + \mu')} + \int(1 + \mu^2) \right]^2} \dots\dots\dots (7)$$

where

- μ = coeff of friction of grain on grain
- μ' = coeff of friction of grains on bin wale

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

5.2.3.2 Silo Classification

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

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

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

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

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

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

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

- Conventional silo
- Instrumentalized silo
- Computerized/ automated silo

Based on structural stability, silo can be classified as:

- Deep silo
- Shallow silo

5.2.4 Controlled Atmosphere (CA)

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

5.2.5 Refrigeration

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

5.2.6 Cold Storage

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

- (i) It retards respiration and other metabolic activities.
- (ii) It controls ripening and retards a aging softening, texture and colour change.
It preserves color and texture.
- (iii) It retards moisture loss and wilting.
- (iv) It controls microbial activities and spoilage.
- (v) It retards spoiling and other undesirable growths.

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

- (i) The product must be in a good condition to be fit for cold storage.
- (ii) Product must be stored immediately after harvest. This is to ensure excessive micro-activity is controlled.
- (iii) In-compactable products must not be stored together neither should you store products that do not have the same ripening rate together.
- (iv) Once a product chills, it should remain at that temperature before use.

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

- (i) Temperature of Storage: Temperature in cold storage must be uniform within the chambers for uniform ripening. Constant temperature must be maintained. Temperature variation must be minimized to prevent spoilage. For temperature sensitive products, permissible temperature variation is $\pm 0.5^{\circ}\text{C}$ while for non-sensitive temperature product, the permissible value is $\pm 1.5^{\circ}\text{C}$.
- (i) Pre-cooling: This is the rapid removal of field heat before storage. It is required for temperature sensitive product, especially fruits. Pre-cooling is achieved either by passing fast cold air through product; or hydro cooling with cold water; or by using ice contact
- (ii) Relative Humidity: Different product could be stored at different relative humidity. Relative humidity affects the keeping quality of product. At low relative humidity, product wilts. It is essential to know the appropriate relative humidity to store your product.
- (iii) Air Circulation and Package Spacing: Packaging should be done in a cold room such that there is a proper air circulation within and around the product. Also a uniform storage conditions must be maintained in the cold room. Other factors such as the respiration rate of product, heat of evolution and the refrigeration rate affect the performance of a cold storage.

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

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

5.2.7 Evaporative Coolant System

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

5.2.8 Hermetic and Nitrogen Storage Systems

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

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

6.0 DRYING OF STORED PRODUCT

Drying is the removal of water molecules to an appreciable storage level. When moisture content is below 9% the process is called dehydration. Drying is achieved by passing hot air stream through the product. The main aims of drying agricultural products include preservation of optimal quality for safe storage; and creation of an environment that would not be favorable for the growth of mould and insect. Drying also eliminates unnecessary water content that contribute to the weight of agricultural material. It also makes the packaging of product easy.

The most important product-factor to be noted during dry is moisture content. Product could be harvested at the optimum harvesting moisture content (about 25%) and reduced to an optimum storage moisture level of 12 – 13%. If crops are harvested at the right time, farmers could save as high as 35% of product.

Drying is essential during storage because of the following reasons:

- Metabolic activities of agricultural materials
- Variations in the ambient conditions
- Activities of micro organisms and insects
- Direct admission of water into storage systems through leaking roof, wall or floor
- Moisture build in storage structures due to condensation and wet spot, etc

A dryer is required to supply heated air for drying during storage. A dryer has the following basic components:

- Heat source to supply heat
- Fan to move the heat
- Duct to channel the heated air
- Insulator to ensure minimal heat loss
- Control systems to regulate air parameters such as temperature, relative humidity, flow rate, enthalpy, entropy, etc

Classification of dryers is based on the following:

- Principle of operation (Natural, mechanical, solar)
- Mode of air & product movement (Co current, counter current, cross flow)
- Level of technology (conventional, semi automated, fully automated)
- Source of heat supply (Solar, electrical, fossil fuel, bio-fuel, etc

7.0 Strategic Food Reserve

This is a national and global approach to ensuring food security and a means of preventing food insecurity. Every nation is expected to formulate policies to support the storage of agricultural and food materials in large scale in order to meet immediate and future national food needs. State and Local Governments are also expected to participate. Such policies must support both the production and preservation of food materials. The implementation of strategic food reserve policies must also be rigorously pursued to ensure the success of such policies.

Strategic food reserve policies must focus on targeted priority crops and food items in the various Local Government and States and in the nation as a whole. The use and management of large scale storage structures for the priority crops and food items must be emphasized in implementation of strategic food reserve policies. Man power development in handling grain storage system is equally essential