COURSE GUIDE

CRP 516
PRODUCE AND POSTHARVEST MANAGEMENT

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INTRODUCTION

CPR 516 is a two (2) unit course on Produce and Postharvest Management. The course consists of 14 units in six (6) modules. The course will give you a good understanding of the fundamental principles upon which postharvest management practices are based. This course guide tells you briefly what the course is all about, and how you can work through these units. It suggests some general guidelines for the amount of time you are likely to spend studying each unit to complete it successfully. It also gives you some guidance on your tutor-marked assignments.

By studying this course, you would be able to understand the climatic and soil factors that affect crop maturity, ripening and senescence, quality and maturity indices of crop products, and such other issues that would reduce post-harvest losses and ensure that the consumer gets value in terms of quantity and quality.

WHAT YOU WILL LEARN IN THIS COURSE

On successful completion of this course, you will be able to:

1. Understand the tropical environment concerning crop maturity, ripening and senescence
2. Understand the physical and chemical indices of quality in fruits, seeds, vegetables, flowers and other crop products
3. Have in-depth studies about the storage and storage life of fruits, seeds, vegetables, flowers and other crop products
4. Know the ideal environment for storage
5. Study the principles of a controlled environment for transit and long term storage
6. Have in-depth studies on the operational equipment for storage and preservation.

COURSE AIMS

The course aims at:

1. Acquainting you with the basic information on postharvest losses, their causes and measures to reduce them.
2. Shelf-life extension of agricultural produce
3. Processing, transportation and storage
   Etc.

COURSE OBJECTIVES

To achieve the set aims, certain overall objectives have been set. In each unit, specific objectives are set, to which you need to pay attention. These are usually included at the beginning of the unit. You can always refer back to the unit's objectives to check your progress.

The overall objectives of the course include the following:

1. To understand the postharvest management of crop production.
2. To identify the most appropriate postharvest technology to apply in processing harvested crop produce.
3. To know how to extend the shelf-life of stored produce.
4. Describe the various postharvest practices for minimizing losses.
5. To understand aspects of a controlled environment for transport and long term storage of harvested crop produce.
6. To know the various equipment and methods of crop storage.

WORKING THROUGH THE COURSE

To complete this course you are required to read the study units and other recommended materials. You will be required to answer some questions based on what you have read in the text to reaffirm the key points. At the end of each unit, there are some tutor-marked assignments (TMAs) which you are expected to submit for marking. The TMA forms part of continuous assessments. At the end of the course, there is a final examination. The course should take you 12 to 13 weeks to complete. You will find listed the component of the course, what you have to do and how you should allocate your time to each unit to complete the course successfully on time.

COURSE MATERIALS

The main components of the course are:

1. Course guide
2. Study units
3. References and Further Reading
4. Tutor-Marked Assignment

COURSE GUIDE

The material you are reading now is called the course guide which introduces you to the course.

COURSE UNITS

Study units in this course are as follows:

Module 1 Tropical Environment in Relation to Crop Maturity, Ripening and Senescence

Unit 1 Climatic Factors in Relation to Crop Maturity, Ripening And Senescence
Unit 2 Soil Factors In Relation to Crop Maturity, Ripening and Senescence

Module 2 Physical and Chemical Indices of Quality in Seeds, Fruits, Vegetables, Flowers and Other Crop Products

Unit 1 Crop Maturity
Unit 2 Quality Indices of Crop Products
Unit 3 Maturity Indices of Crop Products

Module 3 Storage and Storage Life of Seeds, Fruits, Vegetables, Flowers and Other Crop Products

Unit 1 Storage of Farm Products
Unit 2 Strategies for Reducing Post-Harvest Losses
Unit 3 Fundamentals and Principles of Crop Products Processing and Storage
Unit 4 Fresh Storage of Fruits and Vegetables
Unit 5 Storage And Shelf-Life Problems In Crop Products

Module 4 Ideal Environment for Storage

Unit 1 Environmental Factors Affecting Post-Harvest Life of a Crop Produce
Unit 2 Store Environment and Treatment

Module 5 Principles of a Controlled Environment for Transit and Long Term Storage

Unit 1 Principles of a Controlled Environment for Transit
Unit 2 Principles of a Controlled Environment for Long Term Storage

Module 6 Operational Equipment for Storage and Preservation

Unit 1 Storage Structures/Methods
Unit 2 Warehouse/Equipment Management

TUTOR-MARKED ASSIGNMENT (TMA)

There are tutor-marked assignments (TMAs) in each unit. You would have to do the TMA as a revision of each unit. This would help you to have a broad view and a better understanding of the subject. Your tutorial facilitator would inform you of the particular TMA you are to submit to him for marking and recording. Make sure your assignment reaches your tutor on or before the deadline given in the presentation schedule and assignment file. If for any reason, you cannot complete your work on schedule, contact your tutor before the assignment is due to discuss the possibility of an extension.

Extensions will not be granted after the due date unless there are exceptional circumstances. You will be able to complete your assignment questions from the materials contained in this course material and references; however, it is desirable to research more other references, which will give you a broader viewpoint and a deeper understanding of the subject.

FINAL EXAMINATION AND GRADING

The examination will consist of questions that reflect the tutor marked assignments that you might have previously encountered and other questions within the course covered areas. All areas of the course will be covered by the assessment. You are to use the time between finishing the last unit and sitting the examination to revise the entire course. You might find it useful to review yours. Tutor-Marked Assignments before the examination. The final examination covers information from all parts of the course.

REFERENCES AND FURTHER READING

References and materials for further reading are provided at the end of each unit.

MAIN COURSE

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MODULE 1 TROPICAL ENVIRONMENT IN RELATION TO CROP MATURITY, RIPENING AND SENESCENCE

UNIT 1 CLIMATIC FACTORS CONCERNING CROP MATURITY, RIPENING AND SENESCENCE

CONTENTS

1.0 INTRODUCTION

The climatic factors that affect crop maturity, ripening and senescence include rainfall, light, temperature, relative humidity, air, and wind. They are abiotic components of the environment, including topography and soil that influence plant growth and development, maturation, ripening and senescence and consequently the postharvest quality of crop production.

There are mainly three stages in the life span of fruits and vegetables: maturation, ripening, and senescence. Maturation is indicative of the fruit being ready for harvest. At this point, the edible part of the fruit or vegetable is fully developed in size, although it may not be ready for immediate consumption. Ripening follows or overlaps maturation, rendering the produce edible, as indicated by texture, taste, colour, and flavour. Senescence is the last stage, characterized by natural degradation of the fruit or vegetable, as in loss of texture, flavour, etc. (senescence ends with the death of the tissue of the fruit).

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- define maturation, ripening and senescence

- describe elements of climate that affect plant growth and development
- describe elements of climate that affect crop maturation, ripening and senescence
- plan adequately for production of crop bearing in mind the climatic elements that affect plant growth and development
- plan for harvesting of crops at the most optimal time for maximum quality and profitability.

3.0 MAIN CONTENT

3.1 Climatic Factors Concerning Crop Maturity, Ripening and Senescence

i. Rainfall

Rainfall is the most common form of precipitation. The amount and regularity of rainfall vary with location and climate types and affect the dominance of certain types of vegetation as well as crop growth and yield. Through precipitation, water is made available to plants as surface water, soil water or moisture, or groundwater. It comprises about 70-90% of the body or even more on a fresh weight basis, although only a small fraction of the water absorbed is utilised. Most of the water absorbed is lost through transpiration and only about 1 per cent or less is used in the various biochemical processes.

Water is needed by plants from seed germination to plant development. It is a biochemical reactant in the different hydrolytic processes occurring in plants as well as in photosynthesis. It dissolves nutrients to be absorbed and transported and serves as a coolant of the plant through the process of transpiration, the exit of water from plants in the form of vapour. A deficiency or excess of water may influence the postharvest quality of some crops. Extreme water stress reduces yield and quality; mild water stress reduces crop yield but may improve some quality attributes in the fruit, and no water stress increases yield but may reduce post-harvest quality. In strawberries, reduction of water stress by natural rainfall or irrigation during maturation and ripening decreases firmness and sugar content and provides more favourable conditions for mechanical fruit injury and rot. If strawberry plants are over-irrigated, especially at harvest, the fruit is softer and more susceptible to bruising and decay.

Other examples include: heavy rainfall leads to waterlogging and affects adversely the flowers and fruits; at blossoming, rain washes away stigmatic fluid and pollen from stigma; rain before harvesting causes softening of fruits in banana and date palm and induces infection of fruit fly in guava and peach; water deficits have been shown to delay development of floral primordia in both grain sorghum and barley; excess rain or irrigation, leads to brittle and easy damage in leafy vegetables and to reduced tendency to decay; lack of rain or irrigation leads to low juice content and thick skin in citrus fruit; dry condition followed by rain or irrigation leads to growth cracks in tomato or secondary growth in potatoes.

ii. Temperature

Temperature influences all plant growth processes such as photosynthesis, respiration, transpiration, breaking of seed dormancy, seed germination, protein synthesis, and translocation. At high temperatures, the translocation of photosynthesis is faster so that plants tend to mature earlier. In general, plants survive within a temperature range of 0 to 50^oC. Enzyme activity and the rate of most chemical reactions generally increase with the temperature rise. Up to a certain point, there is a doubling of enzymatic reaction with every 10^oC temperature increase. But at excessively high temperatures, denaturation of enzymes and other proteins occur.

Excessively low temperatures can also cause limiting effects on plant growth and development. For example, water absorption is inhibited when the soil temperature is low because water is more viscous at low temperatures and less mobile, and the protoplasm is less permeable. At temperatures below the freezing point of water, there is a change in the form of water from liquid to solid. The expansion of water as it solidifies in living cells causes the rupture of the cell walls. The favourable or optimal day and night temperature range for plant growth and maximum yields varies among crop species. The growth of most crops ceases below a critically low temperature and very high temperatures (usually above 30 – 35^oC) have adverse effects.

Crops are divided into five adaptability groups based on their photosynthetic carbon assimilation pathways (C3, C4 or CAM) and according to the effects of radiation and temperature on photosynthesis. Between the minimum temperature for growth and the optimum temperature for photosynthesis, the rate of growth increases more or less linearly with temperature; the growth rate then reaches a plateau within the optimum temperature range before falling off at higher temperatures. Temperature interacts with radiation; the highest growth potential is achieved with both radiation and temperatures in the optimal range. In many temperate climates and at high altitudes in tropical countries, the temperature for growth is below optimum during part of the growing season.

Low temperatures occurring four to five weeks before harvest cause premature ripening in 'Bartlett' pears. The premature ripening was linked with rising levels of abscisic acid Pre-harvest temperatures also affect the rate of ethylene production during ripening. High production rates of ethylene in 'Bartlett' pears were common in fruit produced in regions with lower temperatures before harvest. The ethylene-forming enzyme (EFE) activity develops earlier in apples exposed to low night temperatures as opposed to fruit that mature under warm night conditions. Furthermore, the daily-hourly average (DHA) temperatures occurring during the last six weeks before harvest were found to influence the acid and sugar content of Pears. Increased acid and sugar levels were reported in pears produced at 17.2ºC and 13.9ºC DHA temperatures, whereas in pears grown at 20.0ºC and 11.7ºC, the ripening capacity was low. The maturity of fruit is highly affected by pre-harvest temperature in the field. For example, grapes on a particular bunch showed differential maturity time due to variation in exposure to sunlight. Fruits born on the exposed side of the sun-ripened faster than those born on the shaded side. These fruits also contained higher sugars and lower acidity than shaded fruits. On the other hand, avocado fruits exposed to the sun on the tree took 1.5 days longer to ripen than those which were on the shaded side. A higher flesh temperature of about 35°C might have slowed down the ripening process in avocado. The same fruits when ethylene-treated exposed fruit being firmer ripened slowly than shaded fruit.

Pre-harvest exposure of fruit and vegetables to direct sunlight leads to several postharvest physiological disorders among which, sunburn or solar injury is the most prevalent temperature-induced disorder in fruit and vegetables (Table 1.1). Photosynthetic activity of the fruit is also hampered by high fruit temperature. In severe cases or frequent exposure lead to browning or blackening of the skin of produce due to tissue failure. This situation results in the complete inactivation of the photosynthetic system. Pre-harvest temperature also has a considerable effect on the quality of fruit during and after postharvest storage. Generally, a higher temperature in the field is associated with higher sugar and lower acidity in the fruit. Grapes and oranges grown at high temperatures contain a higher level of sugar and lower level of tartaric and citric acids respectively than those grown at low temperatures. The firmness of the fruit is also affected by temperature prevailing during fruit growth. Avocado fruits grown on the trees exposed to direct sunlight having temperature around 35°C showed fruits 2.5 times firmer than those grown on the shaded side (20°C) of the tree. The colour development of fruit is also influenced by temperature. Generally, warm days and cool nights during growth are conducive for colour development in fruits.

Table 1.1: Disorders associated with pre-harvest exposure of fruit to high temperature or direct sunlight.

Fruit	**Disorder**	**Symptoms**	**Reference**
Apple	Sunburn	Skin discolouration, pigment breakdown	Bergh et al. (1980), Wűnsche et al. (2000)
Apple	Watercore	Water soaking of flesh	Marlow and Loescher (1984)
Avocado	Sunburn	Skin browning	Schroeder and Kay (1961)
Pineapple	Flesh translucence	Water soaking of flesh	Paull and Reyes (1996); Chen and Paull (2000)
Lime	Stylar end breakdown	Juice vesicle rupture	Davenport and Campbell (1977)
Cranberry	Sunscald	Tissue breakdown	Croft (1995)

Source: Woolf and Ferguson (2000).

iii. Relative Humidity

Relative humidity directly influences the water relations of plants and indirectly affects leaf growth, photosynthesis, pollination, the occurrence of diseases and finally economic yield. Leaf growth does not only depend on synthetic activities resulting from biochemical processes but also on the physical process of cell enlargement. Cell enlargement occurs as a result of turgor pressure developed within the cells. When RH is low, transpiration increases causing a water deficit in the plant. Water deficits cause partial or full closure of stomata and increase mesophyll resistance, blocking the entry of carbon dioxide.

iv. Sunshine

Light is essential in the production of chlorophyll for photosynthesis, the process by which plants manufacture food in the form of *sugar* (carbohydrate). Other plant processes that are enhanced or inhibited by this climatic factor include stomatal movement, phototropism, photomorphogenesis, translocation, mineral absorption, and abscission.

Three properties of light that affect plant growth and development are light quality, light intensity, and day length or photoperiod. **Light quality** refers to the specific wavelengths of light; **light intensity** is the degree of brightness that a plant receives; **day length** is the duration of the day concerning the night period. Increased exposure to light increases fruit size, total soluble solids and flesh firmness as a result of high photosynthetic rates and carbohydrate reserves.

Three relevant aspects of radiation are (i) day length, (ii) its influence on photosynthesis and dry matter accumulation in crops, and (iii) its effects on evapotranspiration. Radiation levels may also be important in the drying and ripening of crops**.** The vegetative growth of most plants increases linearly with solar radiation up to a limit beyond which no further increase occurs. In many tropical areas, water shortages rather than radiation limit growth and the radiation-limited potential are not attained. However, marked seasonal effects on yields may be evident. In temperate countries, radiation is one of the most dominant growth-limiting factors in the winter months. Sunshine influence the pollination, development and colouring of fruit.

Day length: Day length affects photoperiod-sensitive cultivars of crops such as rice, influencing floral initiation and the onset or length of vegetative and reproductive phases of growth and development. The interaction of day length with water availability or temperature can sometimes prove 'class determining at the project level (e.g. in influencing the flowering of sugarcane, flowering and fruiting of mangoes, and in the bulbing and ripening of onions, etc.). The influence of day length on plant development has been extensively studied, and virtually all crop plants as well as many weed species have been classified according to their response to light and the initiation of reproductive growth. In reality, it is both the change in exposure to periods of light and darkness that trigger the mechanisms and results in the classification of plants as short-day (SDP), long-day (LDP), or day-neutral (DNP) for their transformation from vegetative to reproductive growth. Exposure to direct/intermittent sunlight or shade conditions results in variations in the fruit quality as well as its postharvest ripening behaviour and physiology. It also influences the incidence and severity of several physiological disorders and diseases.

It is known that direct sunlight is not essentially required for the synthesis of ascorbic acid in plants. However, the total incidence, amount and intensity of sunlight on the fruits during the entire growing period have a definite influence on the content of ascorbic acid in the fruits. Ascorbic acid is synthesized from sugars generated by photosynthesis in plants. The fruits in the outer parts of the tree canopy receiving direct sunlight have a higher content of ascorbic acid in comparison to fruits growing in shaded regions of the same tree.

The exposure of fruits to excessive sunlight results in the occurrence of sunscald in several fruit crops. The direct exposure of the sunlight on the fruit surface results in pigment degradation in the affected surface area of the fruit. Further, cellular death and collapse of the affected tissue occur if the duration of exposure to sunlight or its intensity is higher than adequate or optimum levels. This influence of high sunlight exposure causing stress to the fruits is mainly thermal in nature, although some bleaching of the chlorophyll pigment can also occur. Some examples of quality degradation due to exposure to excessive or insufficient sunlight are detailed in Table 1.2. Specific disorders like water core in apple and flesh translucence in pineapple were also reported by various workers due to weak and insufficient light presence.

Table 1.2: Quality deterioration due to excess or insufficient sunlight in various fruits

Sl. No.	Name of the fruit	Researchers	Symptoms
1.	Persimmon	George et al. (1997)	Sun Scald
2.	Mandarin	Myhob et al. (1996)	Sun Scald
3.	Pomegranate	Panwar et al, 1994	Sun Scald
4.	Blueberry	Caruso (1995)	Sun Scald
5.	Pineapple	Lutchmeah (1992)	Sun Scald
6.	Apple	Sibbett et al. (1991)	Sun Scald
7.	Banana	Wade et al. (1993)	Sun Scald
8.	Strawberry	Osman and Dodd (1994)	Insufficient light typically results in smaller size fruit and decreases the surface glossiness in strawberry
9.	Apple	Campbell and Marini (1992)	Low sunlight intensity reduces colour development.
10.	Grape	Hummell and Ferree (1997)	-----do----
11.	Strawberry	Saks et al. (1996)	-----do----

Source: Woolf and Ferguson (2000)

v. Wind

Wind serves as a vector of pollen from one flower to another thus aiding in the process of pollination. It is therefore essential in the development of fruit and seed from wind-pollinated flowers as in many kinds of grass. Moderate winds favour gas exchanges, but strong winds can cause excessive water loss through transpiration as well as lodging or toppling of plants. When transpiration rate exceeds that of water absorption, partial or complete closure of the stomata may ensue which will restrict the diffusion of carbon dioxide into the leaves. As a result, there will be a decrease in the rate of photosynthesis, growth and yield.

During growth, wind may also cause damage to the fruit and vegetables. Damage by winds can be grouped into two categories: damage caused by less frequent severe storms; and that caused by frequent winds of intermediate strength. High velocity winds result in damage of leaves and defoliation in leafy vegetables, which cause severe damage to product appearance and marketability. In fruit crops, defoliation leads to smaller size fruit and the development of poor fruit colour in citrus. Mild winds may cause wind scarring disorder due to the rubbing of fruits against twigs. The injured fruit develop tan-to-silvery patches which increase in size with the advancement of maturity. Therefore, the use of windbreaks is advocated for the production of fruit and vegetable in areas subjected to excessive wind.

vi. Air

Air is a mixture of gases in the atmosphere. About 75% of air is found in the troposphere, the innermost layer of the atmosphere which extends about 17 km above sea level at the equator and about 8 km over the poles. In addition, about 99% of the clean, dry air in the troposphere consists of 78% nitrogen and 21% oxygen. The remainder consists of argon (slightly less than 1%), carbon dioxide (0.036%), and traces of other gases. The oxygen and carbon dioxide in the air is of particular importance to the physiology of plants. Oxygen is essential in respiration for the production of energy that is utilized in various growth and development processes. Carbon dioxide is a raw material in photosynthesis.

The air also consists of suspended particles of dust and chemical air pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), sulfur trioxide (SO_3), nitrogen oxides, methane (CH4), propane, chlorofluorocarbons (CFCs), solid particles of dust, soot, asbestos and lead, ozone and many more. These air pollutants such as ozone, sulfur dioxide, fluoride and nitrogen oxides can cause severe damage and reduce the quality of fruit and vegetables during their growth. During the summer season when high temperature and solar radiation prevails the production of ozone in the atmosphere generally increases due to an increase in nitrogen and emission of volatile organic compounds. Ozone enters into the plant system through stomata and causes cellular damage by an increase in membrane permeability and may cause injury. Higher concentration of ozone in the atmosphere also affects the photosynthetic and respiratory processes in plants which ultimately affects postharvest quality in terms of overall appearance, colour, flavour and increase the turnover of antioxidant systems. Elevated atmospheric concentrations of ozone may also lead to yellowing or chlorosis in leafy vegetables, blistering in spinach, alter sugars and starch content in fruit and tuber crops and reduce fruit size by a decrease in biomass production. Fluoride causes discolouration in peach fruit. Similarly, a higher concentration of nitrogen dioxide in the atmosphere results in marginal and interveinal collapse of lettuce leaves. Apart from air pollutants, ions of heavy metals like silver, cadmium, cobalt, magnesium, manganese, nickel, zinc, etc. which may enter into the plant system through soil amendments, runoff, or contaminated irrigation water also can cause deterioration in the quality of fruits and vegetables.

SELF-ASSESSMENT EXERCISE

Tick true (T0 or false (F)

T	F	Ions of heavy metals like silver, cadmium, cobalt, magnesium, manganese, nickel and zinc which may enter into the plant system through soil amendments, runoff, or contaminated irrigation water also cannot cause deterioration in the quality of fruits and vegetables
T	F	Air pollutants such as ozone, sulfur dioxide, fluoride and nitrogen oxides can cause severe damage and reduce the quality of fruit and vegetables during their growth.
T	F	Wind serves does not aid in the process of pollination.
T	F	The use of windbreaks is advocated for the production of fruits and vegetables in areas subjected to excessive wind.
T	F	Day-length refers to the specific wavelengths of light
T	F	Water deficits cause partial or full closure of stomata and increase mesophyll resistance, blocking the entry of carbon dioxide.
T	F	Mild water stress reduces crop yield but may improve some quality attributes in fruits
T	F	Sunburn or solar injury is the most prevalent temperature-induced disorder in fruit and vegetables

T	F	When relative humidity is low, transpiration decreases
T	F	Ozone enters into the plant system through stomata and causes cellular damage by an increase in membrane permeability and may cause injury

4.0 CONCLUSION

Each of the above discussed climatic factors has been shown to produce limiting effects on various growth processes including maturity, ripening and senescence. However, the various climatic factors always operate together and interact with each other under natural conditions. Factors such as temperature stress, drought, nutrient imbalances, shading, air pollution and pests' pressure hasten senescence and have detrimental effects on reproductive growth and yield.

5.0 SUMMARY

Climatic factors that influence plant growth development processes such as photosynthesis, respiration, transpiration, breaking of seed dormancy, seed germination, protein synthesis, and translocation; The roles of these factors in crop maturity, ripening and senescence have been pointed out. A deficiency or excess of the climatic factors may influence the growth and development of crops and postharvest quality.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define crop maturity, ripening and senescence.
2. Describe the effect of five (5) climatic factors on the growth and development of crops.
3. Describe the effect of five (5) climatic factors on crop maturity, ripening and senescence.
4. Give examples of effects of elements of climatic on crop maturity and ripening.
5. List and define three (3) properties of light that affect plant growth and development.

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UNIT 2 SOIL FACTORS CONCERNING CROP MATURITY, RIPENING AND SENESCENCE

CONTENTS

1.0 INTRODUCTION

The soil provides physical anchorage to plants and acts as a storehouse for plants water and nutrients needed. The choice of site for a particular crop depends mainly on two aspects of soil, namely the physical and chemical characteristics of the soil. The soil factors characterizing soil climate are soil air, soil temperature, soil moisture, soil reaction and mineral nutrient supply.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- explain the role of soil factors in crop maturity, ripening and senescence
- explain the influence of soil structure on soil air
- tell the normal level of pH within which plants can do well.

3.0 MAIN CONTENT

3.1 Soil Factors concerning Crop Maturity, Ripening and Senescence

1. Soil air

Soil structure has a profound influence on oxygen diffusion and soil aeration, the composition of soil air and plant diseases. The percentage by volume of soil occupied by air under field conditions or at a given function has been suggested as a measure of soil aeration status. As a rule, the higher the bulk density, the more compact the soil and the smaller the number of pore spaces. This situation restricts the plant growth due to its influence on the root as well as shoot growth. High bulk density inhibits the emergence of seedlings, increases mechanical resistance to root penetration and decreases the oxygen supply to the root system resulting in poor growth and yield of crops.

The composition of the air varies from that of the atmosphere in moisture and carbon dioxide content. While water vapour content on soil is large compared to that of the atmosphere, the CO_2 content is frequently greater than 0.3% and can be so high as to exclude O_2 completely. While some pathogens like *Ophiobolus gramineous* cannot survive in waterlogged soils, root rot of several crops caused by *Fusarium sp*., *Rhizoctonia sp* and *Aphanomyces* are most severe in soils of poor drainage.

2. Soil moisture

Adequate soil moisture during the pre-harvest period is essential for the maintenance of Post-harvest quality. Water stress during the growing season can affect the size of the harvested plant organ, and lead to soft or dehydrated fruit that is more prone to damage and decay during storage. On the other hand, vegetables experiencing an excess of water during the growing season can show a dilution of soluble solids and acids, affecting flavour and nutritional quality. Excess moisture on the harvested vegetable can also increase the incidence of postharvest diseases. To minimize the amount of water on the harvested vegetable brought into storage, it may be beneficial to choose surface or subsurface irrigation rather than overhead irrigation. Vegetables harvested in the early morning, during rainy periods, and from poorly ventilated areas can also experience increased postharvest decay.

3. Soil temperature

Soil temperature varies seasonally and daily due to changes in radiant energy and energy changes taking place through the soil surface. It governs the soil physicochemical and biological processes and also influences processes of gas exchange between the atmosphere and the soil.

Environmental factors affect soil temperature by either controlling the amount of heat supplied to the soil surface and the amount of heat dissipated from the soil surface down the profile. Soil temperature alters the rate of organic matter decomposition and mineralization of different organic materials. It also affects soil water content, its conductivity and availability to plants. It is therefore a major determinant of processes that affect plant growth and development.

Soil temperature more closely correlates with crop development than air temperature. Plant processes, including nutrient and water uptake, as well as the initiation, branching and orientation of root growth, are also dependent on soil temperature. The susceptibility of crops to diseases is also influenced by soil temperature.

4. Soil reaction

The availability of plant nutrients depends on soil reaction. Acid soils with high ions, aluminium and manganese decrease the availability of phosphorus. Availability of molybdenum declines with a decrease in soil pH.

Plants do not thrive in extreme conditions (unless they have adapted). As with excess heat, water or light, an excessively high pH soil will not provide an ideal environment for most plants. Creating a high pH condition by feeding a plant the wrong type of food will have an adverse effect. Acidic soils have low pH, and this affects the plant's ability to absorb essential nutrients from the soil. Normal ranges for soil pH are between 5 and 8.5, below or above which problems will occur. For example, at pH levels below 5, manganese and aluminium can become toxic growing in such soils. Plants can get overloaded with these nutrients and cannot process the excess quickly enough, leading to plant death. Soils with low pH may cause a release of aluminium that can stunt plants growth and alter nut nutrient intake. Some plants may also suffer manganese and iron toxicity that causes yellow spots and leads to browning and leaf death. Other symptoms may include wilting of leaves, stunted growth, blighted leaf tips, yellowing of foliage or other leaf discolouration and poor stem development.

5. Mineral nutrient supply

The capacity of the soil to supply essential plant nutrient elements has a profound influence on crop production. The involvement of different mineral nutrients in various aspects of crop physiology, ripening and storability indicate the significance of the endogenous levels of mineral nutrients for the crops. Quality parameters of crops are also under the influence of the status of mineral nutrients in the grain or fruit as well as the grain/fruit-bearing plant, and they (mineral nutrients) also have roles in determining the extent and severity of different physiological disorders and pathological problems of grains and fruits.

SELF-ASSESSMENT EXERCISE

Fill in the blank spaces:

i. As a rule, the higher the bulk density, the more compact the soil and the …………….. the number of pore spaces.
ii. Soil ……………….. has a profound influence on oxygen diffusion and soil aeration.

4.0 CONCLUSION

The soil factors discussed in this unit are very important in crop maturity, ripening and senescence. Deficiencies or excesses of any of them can result in delayed or maturity and related disorders that can limit the storage life of much agricultural produce.

5.0 SUMMARY

Soil has a direct relation to the growth, development and quality of crop products. The quality and post-harvest shelf life of crops are also affected by soil air, soil temperature, soil moisture, soil reaction and soil nutrition as discussed in this unit. Plants do not thrive in extreme conditions (excess or deficient) unless they have adapted.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Enumerate the effect of excess nitrogen application on crops
2. Enumerate the nitrogen deficiency disorder on crops.
3. How do environmental factors affect soil temperature?
4. Enumerate disorders associated with Ca deficiency.
5. Explain the essential role of soil moisture in the physiological processes of growth and development of the crop.

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MODULE 2 PHYSICAL AND CHEMICAL INDICES OF QUALITY IN FRUITS, SEEDS, VEGETABLES, FLOWERS AND OTHER CROP PRODUCTS

UNIT 1 CROP MATURITY

CONTENTS

1.0 INTRODUCTION

The life cycle duration of all crops is important to their management for maximum economic yield. For most agronomic crops maturity ratings refer to the time from germination until physiological maturity. Phyto-hormones play a vital role in plant maturation, beginning with germination and in some cases ending with product consumption. Maturation is closely associated with senescence.

Vegetables are harvested over a wide range of maturities, depending upon the part of the plant used as food. Produce harvested too early may lack flavour and may not ripen properly, while produce harvested too late maybe fibrous or overripe.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- define crop maturity and give suitable examples of indicators of maturity in some crops
- discuss various types of crop maturity.

3.0 MAIN CONTENT

3.1 Crop Maturity

Maturity at harvest is the most important determinant of storage life and final fruit quality. Immature fruit is highly susceptible to shrivelling and mechanical damage, and are of inferior flavour quality when ripe. Overripe fruit is likely to become soft and mealy with an insipid flavour soon after harvest. Fruit picked either prematurely or too late, are more susceptible to postharvest physiological disorders than are fruit picked at the proper stage of maturity.

Generally, crops are harvested when they are said to be “mature”. The best time to harvest a crop depends on several factors, including the economic part (the product), utilization of the product, and postharvest storage.

1. **The economic part:** The economic part or product of the crop plant can be the root, leaf, stem, grain, or other parts. These plant parts have different times when it is best to harvest them. Crops should be harvested when the desired product is at its peak quality and quantity.
2. **Utilization:** The economic product may come from the same part of the plant, but on one occasion it may be desirable to harvest it fresh while on another it may be best to harvest it dry. Corn, for example, maybe harvested fresh or dry depending on the intended use.
3. **Storage method:** Harvested products often require some form of storage at the site of production while awaiting transportation to the market. The product may deteriorate in storage if harvested at an improper moisture content. Cold storage is required for grains with high moisture content. Many grain producers have supplementary drying facilities for drying the harvested product to a safe moisture content for storage.

The keyword for harvesting seeds is timeliness. Harvesting must not take place too early, nor too late. Too early means that high moisture content will make dry storage of the seeds impossible. Too late will result in losses through disease and insect infestation, birds, shattering or spoilage through the rain. Too late will also increase the brittleness of the seeds, which makes them more likely to break when the crop is handled. Because of the higher value of a seed crop, it can be worth the extra trouble to harvest a little early and dry the seed artificially. This will eliminate most of the dangers mentioned. When you investigate drying methods that have not been specifically designed for seed, bear in mind that too much heat is the surest way to kill the seed. A well-ventilated place in light shade is best, and the seed should be regularly turned. You should also be careful to stop in time, and not let the seed get too dry. If you want to rely on field drying, you must have planned your planting time so that harvesting can take place in the dry season.

There are several operational and technical categories of crop maturity. The common ones are physiological maturity, harvest maturity, storage maturity and commercial or horticultural Maturity.

3.1 Physiological Maturity

In most crops, the seed reaches maturity a while before normal harvesting time. The grain has been filled, the embryo is complete, and all that happens from then on is the loss of water. We say that the seed is then *physiologically mature*. Physiological maturity is defined as the time when dry matter accumulation in the kernels or seeds ceases, in other words, the grain stops "filling." It describes that period when sexually induced reproductive growth has ceased. In theory, a crop can be harvested any time after this point, provided you are equipped to deal with the high moisture content.

In most pulses, physiological maturity is reached when the pods start to change colour. The plants can then be pulled up and put in windrows or on racks to dry. This helps to ensure that all pods are ready for threshing at about the same time. In cultivars with a long flowering period and pods of widely differing ages, you will have to compromise between losing seeds from the oldest pods due to shattering, and harvesting the youngest pods too early. The first set of pods are usually of the best quality, so it is usually better to save them rather than the youngsters. Groundnuts do not allow for simple inspection of the pods. There is no alternative to digging up a few plants when you think the time is nearing and checking if the seeds are free in the pod and if the skin on the seeds (in the case of peanuts) has turned colour.

Examples

1. Black layer formation at the tip of the kernel is a good indicator of physiological maturity in corn and grain sorghum. In maize, you can see the black layer by breaking a seed off the cob, removing the bits of fibrous and papery tissue at the top, and looking as it were into the seed from the point where it was attached.
2. A French bean pod of okra is at its physiological maturity when seeds are fully developed and the pod will dehisce with little pressure.
3. In rice and wheat, the golden yellow colour of the grain and senescence of the lower leaves indicate physiological maturity.

4. In groundnut, the development of black colour in the inner shell of the pod signifies physiological maturity.

Physiological maturity is always followed by senescence. At physiological maturity, increasing production inputs does not produce any gain in yield. In ingrain crops, there is a cessation in growth and grain filling at this stage. The grains at this stage have about 40% moisture content and are of hard dough consistency. If the grain is harvested before its physiological maturity, it will have a low dry matter, poor quality and shrivel upon drying.

3.2 Harvest Maturity

Harvest maturity for a crop is when the product of interest is at peak quality and quantity. Farmers normally determine when harvesting a crop will produce the highest yield of the product of interest by certain indicators acquired through experience. In most cases, harvesting grain crops is done at 15 – 18% moisture content. Even if they are harvested at a higher moisture content, they should be dried to 13 – 14% moisture content for safe storage.

When crops are grown for forage, the best time for harvest is when they have attained maximum vegetative yield, coupled with high quality. It is best to cut cereal crops for storage when the heads are emerging.

The harvest maturity of fruits and vegetables depends upon the purposes for which they are harvested. For the local market and processing, fully coloured tomato fruits are harvested. However, for a distant market fruit, it is best to harvest when has started developing colour. The post-harvest quality and storage life of fruit appear to be controlled by maturity. If the fruits are harvested at a proper stage of maturity the quality of fruit is excellent.

Poor quality and uneven ripening are caused by early harvesting and late harvesting results in extremely poor shelf life. The fruit must be at the right stage of maturity with no physical damage. Various Maturity Indices such as some damage from fruit set, visual indicators, size, shape, colour, appearances, texture, lenticel number, specific gravity starch contain soluble solids, sugar, acid ratio and oil content are used to determine the maturity of fruits.

Sometimes, it is desirable to hasten the time of crop harvesting. After a grain crop has reached physiological maturity, any delay in harvesting may cause deterioration in quality and quantity. Several direct and indirect methods may be adopted to hasten the time of crop harvesting.

Direct methods - the direct methods include:

i. **Defoliation and desiccation.** Once a plant has attained physiological maturity, it cannot accumulate any more dry matter. Leaving it in the field longer predisposes it to weather. Sometimes, inclement weather threatens the quality of the harvest, thereby forcing the producer to adjust the harvesting schedule. Such adjustments include inducing early harvest maturity by applying a defoliant (a defoliant causes leaf drop) or desiccant (a desiccant causes the plant to dry out in the field and die).

   Examples

1. In cotton production, green leaves tend to stain the fibres. Defoliation of cotton before mechanized harvesting reduces not only the amount of undesirable plant debris in the harvested fibre but also the chance of tainting it with plant pigments.
2. In haymaking, a chemical treatment (say with endothelial) hastens the drying of the plant material in the field.

ii. **Topping:** topping is the pre-harvest reduction of vegetative material (mainly leaves). This slows photosynthetic activity and hastens the drying of the economic part (e.g., pods).

Indirect method – generally, crops are harvested when the conditions of the economic product are such that it can be stored for a reasonable period without deterioration. However, if the producer has a drying facility, the product can be harvested sooner than normal harvest maturity, and then dried to storable moisture content later.

3.3 Commercial or Horticultural Maturity

This is the stage of development when the plant or plant part possesses the prerequisites of utilization by the consumer for a particular purpose. The horticultural maturity of fruits and vegetables depends upon the purpose for which they are harvested.

Example: The French bean pod of okra pod is matured when it is tender with maximum size, as per horticultural maturity.

3.4 Storage Maturity

When there is no scope for postharvest drying, the crop is harvested at a stage when it can be directly stored. For grains, this means allowing the ripening to occur to less than 14% moisture content.

Sometimes, inclement weather, equipment failure, or other eventualities delay the harvesting of field crops. Crops may be harvested prematurely or when over-mature, each with its attendant consequences. The consequences could be:

a. **Crop yield reduction:** Harvesting early means crop development and filling are curtailed pre-maturely. The attainable dry matter will not be realized, leading to a lower yield. Delayed harvesting may cause lodging or crinkling of the stem and shattering of the seeds/grains. These events lead to increased harvest losses.

b. **Grain quality reduction:** Grains harvested pre-maturely are shrivelled and have low starch content. Delayed harvesting causes field weathering of grains, leading to reduced germination and storability. Delayed harvesting may also cause certain products to be fibrous and undesirable.

c. **Loss of value:** weathered grain attracts low prices. It is generally rated low on the quality grading scale

SELF-ASSESSMENT EXERCISE

i. List four (4) categories of crop maturity.

ii. List three (3) consequences of harvesting crops prematurely or when over-matured.

iii. Physiological maturity is always followed by …………………………..

iv. What are the major determinant of horticultural maturity in fruits and/or vegetables?

4.0 CONCLUSION

Harvesting crops at the proper stage of maturity is of paramount importance for attaining desirable quality. The maturity of crops at harvest will significantly affect their quality along the post-harvest value chain

5.0 SUMMARY

The common types of crop maturity are physiological maturity, harvest maturity, storage maturity and commercial or horticultural Maturity. Sometimes, crops may be harvested prematurely or when over-matured due to certain circumstances. The consequences of premature or over-mature harvest include crop yield reduction, grain quality reduction and loss of value.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Harvesting crops prematurely or when over-matured has consequences. Discuss.
2. What are the disadvantages of harvesting a grain crop before physiological maturity?
3. Distinguish between physiological maturity and harvest maturity.

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UNIT 2 QUALITY INDICES OF CROP PRODUCTS

CONTENTS

1.0 INTRODUCTION

Quality can be defined simply as a "degree of excellence or superiority". The term "quality" is a complex perception felt by the consumer in different ways. It is a combination of characteristics, attributes and properties which give the commodity value to humans for food. The perception of quality varies among producers and consumers. Producers are more concerned with commodities that have a good appearance and few visual defects but, for them, a good cultivar must rank high in yield, disease and pest resistance, ease of harvest and shipping/transporting quality. However, consumers are interested in products that have a good appearance, firmer, good flavour and nutritive value. Although consumers purchase products based on appearance, their repeat purchase depends on good edible quality.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- define crop quality and outline crop quality indices
- discusses various areas of crop quality concerns that affect the consumer.

3.0 MAIN CONTENT

3.1 Quality Indices of Crop Products

Quality i.e. the degree of excellence or superiority of fresh fruits and their products is a combination of attributes, properties or characteristics that give each commodity value in terms of human food. The relative importance of each quality component depends upon the commodity and its intended use (e.g., fresh or processed) and varies among producers, handlers and consumers. To producers, a given commodity must have a high yield and good appearance, must be easy to harvest and must withstand long-distance shipping transportation to markets. Appearance, firmness, and shelf-life are important from the point of view of wholesale and retail marketers.

Consumers judge the quality of fresh fruits based on appearance including freshness and firmness at the time of initial purchases. Subsequent purchases depend upon the consumers' satisfaction in terms of flavour (eating) quality of the product. Consumers are also concerned about the nutritional quality of fresh fruits, which are only colourful and flavorful components of our diets, but also a good source of energy, vitamins, minerals, dietary fibres and many bioactive compounds that enhance human health.

Loss of quality

Quality is difficult to measure objectively unless it can be related to economic value. Quality of produce is assessed in different ways according to the circumstances considered important by local traders and consumers. Generally, quality is assessed and products graded based on appearance, shape, size, etc., but biochemical indices (e.g. sugars, acidity, smell and flavour) are sometimes important quality parameters, especially for some perishable commodities. Foreign matter content and contaminants are factors in the loss of quality in grains. Foreign matter may include insect fragments, grass, rodent hairs and excreta, weed seeds, parts of plants, earth, stones and glass. Contaminants, which cannot be readily removed, include soluble excretions of pests, oils, pesticides, pathogenic organisms spread by rodents, and toxins arising from fungal infections. The higher the standard set by the consumer the greater will be the potential for loss.

Nutritional loss: This, in a sense, is the product of the quantitative and qualitative losses; but more specifically, it is the loss in terms of nutritional value to the human population which, in turn, will depend on the nutritional status of that population. Weight loss of grains during storage is a measure of food loss, but the nutritional loss may be proportionately larger owing to selective feeding by pests. Rodents and some insect larvae, for example, *Ephestia* and *Plodia*, feed preferentially on the germ of the grain, removing a large percentage of the protein and vitamin content. Weevils feed mainly on the endosperm and reduce the carbohydrate content. Many pests eat the bran of cereals, thereby reducing the vitamin content; *Liposcelis* spp (Psocidae) feed selectively on the germ and bran of rice (Pike 1994). High moisture content and the associated growth of micro-organisms also lead to changes in the vitamin content of grain. Bruchids feed on the cotyledons of pulses (Haines 1991) and loss of protein due to such infestation may be serious as up to 25% of the dry bean matter may be crude protein.

Loss of seed viability: This relates to loss in seed germination – important because of its effect on future food supplies. More care is usually exercised in the storage of seed grain owing to its greater potential value. Loss may be caused by changes in temperature, moisture content, excessive respiration, light, insect infestation and, perhaps, the methods used to control an infestation. Insects that selectively attack the germ will cause a greater loss in germination than others. Loss of seed can be determined using standard germination tests (ISTA 1966).

Commercial losses: Commercial losses may occur as a direct consequence of any of the foregoing factors, or indirectly as the cost of preventive or remedial actions required, including the costs of the necessary equipment. Commercial losses may be expressed in terms of monetary loss, a loss of goodwill and loss due to legal action. Commercial losses may affect inter-country trade: for example, after an outbreak in Tanzania of the destructive maize pest *Prostephanus truncatus*, Malawi and Somalia refused to accept Tanzanian maize because of the risk of the insect spreading to these countries (Tyler *et al.* 1990). All of these losses can be reduced. In most cases knowledge and experience can be major factors and improvement may be relatively rapid. However, in cases where attitudes or beliefs are involved, such as consumer preference, much slower progress must be expected.

SELF-ASSESSMENT EXERCISE

Tick true (T) or false (F):

T	F	Crop quality is easy to measure objectively even if it is not related to economic value
T	F	Commercial losses may be expressed in terms of monetary loss, a loss of goodwill and loss due to legal action
T	F	Knowledge and experience are not important factors in reducing commercial losses in crop production
T	F	Consumers judge the quality of fresh fruits based on appearance including freshness and firmness at the time of initial purchases
T	F	Foreign matter content and contaminants are factors in the loss of quality in grains

4.0 CONCLUSION

The quality of crops is governed by many factors. The combined effect of all decides the rate of deterioration and spoilage. These factors if not controlled properly, lead to postharvest losses on large scale.

5.0 SUMMARY

To the producer, a qualitative commodity must have a high yield and good appearance, must be easy to harvest and must withstand long-distance shipping/transportation to markets. Consumers, however, judge the quality of fresh fruits based on appearance including freshness and firmness at the time of initial purchases. Subsequent purchases depend upon the consumers' satisfaction in terms of flavour (eating) quality of the product.

6.0 TUTOR MARKED ASSIGNMENT (TMA)

1. What are the indices of crop quality?
2. Write short notes on the loss of crop quality.
3. Define crop quality.

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UNIT 3 MATURITY INDICES OF CROP PRODUCTS

CONTENTS

1.0 INTRODUCTION

With a few exceptions, all fruits attain optimal eating quality when allowed to ripen on the plant. Some fruits are, however, picked at a mature but unripe stage of development to allow them to withstand post-harvest handling conditions when shipped/transported over long distances. Maturity indices for such fruit are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide flexibility in marketing. Fruit can be divided into two groups:

Those that are incapable of continuing their ripening process once removed from the plant, and 2. Those that can be harvested at the mature stage and allowed to ripen off the plant.

Group 1 includes cane berries, cherry, citrus fruits, grape, lychee, pineapple, pomegranate and strawberry. Group 2 on the other hand, includes apple, apricot, avocado, banana, cherimoya, guava, kiwifruit, mango, nectarine, papaya, passion fruit, pear, peach, persimmon, plum, quince and sapodilla Fruit of the Group 1 category, produce very small quantities of ethylene and do not respond to ethylene treatment except in terms of de-greening (removal of chlorophyll); these should be picked when fully-ripe if good flavour quality is to be ensured. Fruit of the Group 2 category, on the other hand, produce comparably larger quantities of ethylene which is associated with their ripening and undergo more rapid and uniform ripening upon exposure to ethylene. Many vegetables, in particular leafy vegetables and immature fruit-vegetables (such as cucumbers, sweet corn, green beans, peas, and okras), attain optimum eating quality before reaching full maturity.

Maturity indices are the sign or indication of the readiness of the commodity for harvest. It is the basis for determining the harvest date. Using maturity index helps ensure sensory quality, adequate postharvest shelf life, facilitates scheduling of harvest and packing operations, and facilitate marketing.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- describe the various maturity indexes for some fruits and vegetables
- explain the importance of maturity indices and their impact on shelf-life and quality.
- determine the maturity stage of fruits and vegetables using subjective and objective maturity indices.

3.0 MAIN CONTENT

3.1 Maturity Indices of Crop Products

3.3.1 Physical indices of Maturity

i. **Skin colour:** This factor is commonly applied to fruits since skin colour changes as the fruit ripens or matures. Some fruits exhibit no perceptible colour change during maturation, depending on the type of fruit or vegetable. Assessment of harvest maturity by skin colour depends on the judgment of the harvester, but colour charts are available for cultivars, such as apples, tomatoes, peaches, chilli peppers, etc. However, some fruits do not exhibit any perceptible colour changes during maturation, and thus this parameter cannot be effectively used. Colour changes also differ among different cultivars of the same fruit. For example, the Hayward cultivar of kiwifruit maintains its green flesh during maturation while the 'Sanuki Gold' cultivar changes gradually to golden-yellow. Some cultivars of avocado also maintain their green skin colour during maturation.

ii. **Shape:** The shape of fruit can change during maturation and can be used as a characteristic to determine harvest maturity. For instance, a banana becomes more rounded in cross-sections and less angular as it develops on the plant. Mangoes also change shape during maturation. As the mango matures on the tree the relationship between the shoulders of the fruit and the point at which the stalk is attached may change. The shoulders of immature mangoes slope away from the fruit stalk; however, on more mature mangoes the shoulders become level with the point of attachment, and with even more maturity the shoulders may be raised above this point.

iii. **Size:** Changes in the size of a crop while growing are frequently used to determine the time of harvest. For example, partially mature cobs of *Zea mays saccharata* are marketed as sweet corn, while even less mature and thus smaller cobs are marketed as baby corn. For bananas, the width of individual fingers can be used to determine harvest maturity. Usually, a finger is placed midway along the bunch and its maximum width is measured with calliper; this is referred to as the calliper grade.

iv. **Aroma:** Most fruits synthesize volatile chemicals as they ripen. Such chemicals give the fruit its characteristic odour and can be used to determine whether it is ripe or not. These doors may only be detectable by humans when the fruit is completely ripe, and therefore has limited use in commercial situations.

v. **Fruit opening:** Some fruits may develop toxic compounds during ripening, such as ackee tree fruit, which contains toxic levels of hypoglycin. The fruit splits when it is fully mature, revealing black seeds on yellow arils. At this stage, it has been shown to contain minimal amounts of hypoglycin or none at all. This creates a problem in marketing; because the fruit is so mature, it will have a very short post-harvest life. Analysis of hypoglycin A‘(hyp) in ackee tree fruit revealed that the seed contained appreciable hyp at all stages of maturity, at approximately 1000 ppm, while levels in the membrane mirrored those in the arils. This analysis supports earlier observations that unopened or partially opened ackee fruit should not be consumed, whereas fruit that opens naturally to over 15 mm of lobe separation poses a little health hazard, provided the seed and membrane portions are removed.

vi. **Leaf changes:** Leaf quality often determines when fruits and vegetables should be harvested. In root crops, the condition of the leaves can likewise indicate the condition of the crop below ground. For example, if potatoes are to be stored, then the optimum harvest time is soon after the leaves and stems have died. If harvested earlier, the skins will be less resistant to harvesting and handling damage and more prone to storage diseases.

vii. **Abscission:** As part of the natural development of a fruit an abscission layer is formed in the pedicel. For example, in cantaloupe melons, harvesting before the abscission layer is fully developed results in inferior flavoured fruit, compared to those left on the vine for the full period.

viii. **Firmness:** A fruit may change in texture during maturation, especially during ripening when it may become rapidly softer. These changes can be used to determine the harvest time. Excessive loss of moisture may also affect the texture of crops. These textural changes are detected by touch, and the harvester may simply be able to gently squeeze the fruit and judge whether the crop can be harvested.

Today sophisticated devices have been developed to measure texture in fruits and vegetables, for example, texture analyzers and pressure testers; they are currently available for fruits and vegetables in various forms. A force is applied to the surface of the fruit, allowing the probe of the penetrometer or tetrameter to penetrate the fruit flesh, which then gives a reading on firmness. Hand-held pressure testers could give variable results because the basis on which they are used to measure firmness is affected by the angle at which the force is applied. Two commonly used pressure testers to measure the firmness of fruits and vegetables are the Magness-Taylor and UC Fruit Firmness testers. A more elaborate test, but not necessarily more effective, use instruments like the Instron Universal Testing Machine. It is necessary to specify the instrument and all settings used when reporting test pressure values or attempting to set standards.

ix. **Juice content:** The juice content of many fruits increases as the fruit matures on the tree. To measure the juice content of the fruit, a representative sample of fruit is taken and then the juice is extracted in a standard and specified manner. The juice volume is related to the original mass of juice, which is proportional to its maturity.

x. **Number of days from fruit set:** Fruit set refers to the transition of a flower to fruit after fertilization. It usually involves rapid cell division and expansion of the ovary and the development of seeds. In some fruits, the time taken between fruit sets until the fruit starts showing signs of maturity has been recorded, which can be used to determine harvest time.

For instance, in Alphonso and pairi mango varieties, it takes about 110 to 125 days after the fruit is set for surface colour to change from dark green to olive-green and flesh colour from white to pale yellow. On the other hand, it has been reported that Langra and Mallik took 84 and 96 days after fruit set respectively to attain harvest maturity.

xi. **Specific gravity:** The specific gravity of fruit can be considered an index for maturity grading. Water has a specific gravity of 1.00, and common salt solution (2.5% NaCl) has a specific gravity of 1.02, and both are used in the maturity grading of mango fruits (Kapsa and Katrodia 1997). e.g., the specific gravity of mango range between 1.01-1.02.

3.3.2 Chemical indices of Maturity

i. **Sugars:** In climacteric fruits, carbohydrates accumulate during maturation in the form of starch. As the fruit ripens, starch is broken down into sugar. In non-climacteric fruits, sugar tends to accumulate during maturation. As the fruit ripens starch is broken down to sugars. Measurement of sugars indicate the stage of maturity or ripeness, sugar constitutes the major portion of soluble solid of the fruit juice. Usually, the sugar content is measured in total soluble solids content using a Brix hydrometer or refractometer.

ii. **Starch:** Starch content in developing fruit of pear and apple provides harvest maturity. Starch content is measured using iodine to qualitatively determine the amount of starch. This method is used in determining the maturity of pear cultivars, whereby the fruit is cut into two and dipped into a solution containing potassium iodide and iodine.

iii. **Acidity:** In many fruits, the acidity changes during maturation and ripening, and in the case of citrus and other fruits, acidity reduces progressively as the fruit matures on the tree. Maturity indices are important for deciding when a given commodity should be harvested to provide some marketing flexibility and ensure the attainment of acceptable eating quality to the consumer. These two goals are not always compatible. The necessity of shipping/transporting fruits long distances often resulted in harvesting them at less than ideal maturity. This, in turn, has resulted in less than optimum quality to the consumer. Most maturity indices are also factors of quality, but many important quality indices are not used in determining the optimum harvesting stage. The flavour quality of fruits cannot be accurately determined by the appearance factor alone. Also post-harvest quality of fruits based on flavour is generally shorter than their postharvest-life based on appearance (such as colour and absence of defects and decay).

SELF-ASSESSMENT EXERCISE

i. The shape of fruit can change during maturation and can be used as a characteristic to determine harvest maturity. Discuss.

ii. The necessity of shipping/transporting fruits long distances often resulted in harvesting them at less than ideal maturity. True/False (tick your choice).

iii. In climacteric fruits…..………………….. accumulate during maturation in the form of …………………………..

4.0 CONCLUSION

Maturity indices are important for deciding when a given commodity should be harvested to provide some marketing flexibility and ensure the attainment of acceptable eating quality to the consumer.

5.0 SUMMARY

The deteriorative processes which ultimately lead to complete loss of organization and functioning of the plant or its parts are known as Senescence Three stages in the life span of fruits and vegetables could be distinguished as maturation, repining and senescence. Maturity indexes for most fruits and vegetables could be any or combination of the following such as changes in colour, shape, size, aroma, fruit opening, abscission, leaf changes, firmness, juice content, sugar and acidity.

Accurate, efficient, and effective maturity indices must be applied to ensure high quality at all levels along the value chain. It is worth noting that a single maturity index cannot predominately determine the maturity of fruits. Therefore, it is advisable to use different parameters simultaneously to improve the accuracy of the determinations. Furthermore, one maturity index cannot be applied across all cultivars of the same crop. This is because there are slight differences among the cultivars.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Distinguish physiological maturity from harvest maturity.
2. Discuss the physical indices of crop maturity.
3. Discuss the chemical indices of crop maturity.

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MODULE 3 STORAGE AND STORAGE LIFE OF SEEDS, FRUITS, VEGETABLES, FLOWERS AND OTHER CROP PRODUCTS

UNIT 1 STORAGE OF FARM PRODUCE

CONTENTS

1.0 INTRODUCTION

Storage is the art of keeping the quality of agricultural materials and preventing them from deterioration for a specific period, beyond their normal shelf life. Different crops are harvested and stored by various means depending on the end utilization. Whether the seed will be used for new plantings the following year, for forage being processed into livestock feed, or even for crops to be developed for special use, the grower must be aware of harvesting and storage requirements toward a quality product. After determining the prescribed use for the crop, the timing for harvest and storage is of important consideration. Along with an assessment of when to harvest, the farmer needs to determine the method of harvesting.

Farm products are subject to attack by insect pests after harvesting if they are not properly kept. To reduce the incidence of pests and to avoid spoilage, agricultural products are kept in special places either for short or long periods depending on when they are sent to the market or used as input during the next planting season. During storage pests and micro-organisms are effectively kept from harvested agricultural products to avoid spoilage.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- define storage
- state the reasons for storing farm produce
- state the different types of storage of farm produce
- discuss the different types of storage and the bases for classifying them into those types.

3.0 MAIN CONTENT

3.1 Storage of Farm Products

Storage refers to the process of keeping agricultural products for future use as food, raw materials, fuel or to maintain their original state. It is the phase of the postharvest system during which the products are kept in such a way as to guarantee food security other than during periods of production.

3.1.1 Reasons for Storing Farm Produce

The reasons for storing farm products include the following:

1. To ensure that food is available throughout the year at affordable prices.
2. To reduce to the barest minimum the amount of food spoilage caused by pests and diseases attack.
3. **To preserve planting material for the next planting season.**
   Part of the harvest is used as propagation material for the next crop. If seeds or tubers are not stored well, some will not germinate when planted, which means the farmer will have to plant many more to get enough plants. The seed grains may also grow at different speeds, which will cause problems for cultivating and harvesting the crop.
4. **To maintain or preserve the quality of food.**
   It is important to have enough food, but to stay healthy it is also important to have food that is of good quality. Farmers and their families can see whether they will run out of grain to eat before the next harvest, but the loss of food quality is more difficult to measure. Some insects eat out the best parts of the grain, which contain the vitamins and minerals that make the food nutritious. Farmers may not see this loss, and therefore need to know how to prevent it. Lack of nutritious food can lead to many problems, including sickness and malnutrition.

4. To ensure adequate supply of raw materials to industry for processing.
5. Provision for large scale processing
6. Price control and regulation
7. Optimization of farmers gain / financial empowerment of farmers
8. Opportunity for export

3.1.2 Types of Storage

Storage types can be classified based on the following factors:

1. Duration of Storage
2. Size or Scale of Storage
3. Principle of Storage

1. Classification based on the duration of storage

Storage systems are classified in terms of duration of storage as short term storage, medium-term storage and long term storage.

Short 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 a short term. High loss of quality is associated with highly perishable crops in this storage except controlled systems are used.

Medium-term storage: 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: 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. Classification based on a scale of storage

Storage systems are classified in terms of size or scale of storage as small scale storage,medium-scale storage and large scale storage.

Small scale storage: Small scale storage systems have the 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:** 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 a capacity beyond 50 tons. Some are used in breweries for the temporary storage of spent grains. **Medium-scale storage:** Large scale storage can accommodated stored material in 100s and1000s of tons. It is used either for the temporary or permanent storage of a very large quantity of various products. It has a very high initial cost but eventually reduces the overall unit cost of production.

3. **Classification Based on Principle of Operation of the Storage System**

Storage systems can be classified in terms of a principle of operation. These include physical storage, chemical storage and biological storage.

Physical storage: Physical storage utilizes physical principles to achieve storage and preservation of 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 a controlled environment.

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

Biological storage: Biological storage utilizes biological agents, especially micro-organisms, 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 biotechnology in agriculture.

3.1.3 Storage Considerations

Most agricultural products are not consumed immediately after harvest for reasons given in 3.1.3.1 but have to be stored for some time. The challenge in storing agricultural products is to prevent them from deteriorating and losing quality. The following considerations should be made:

1. Sometimes not picking or harvesting products until they can be consumed is an option for tuber and bulb crops and some vegetables and fruits. Most products, however, need to be harvested right away at maturity, to prevent their quality from decreasing too much and to reduce the chances of infestation by pests and diseases or theft.
2. Leaving the products in the field after harvesting is possible and desirable in some cases, but it is always risky because the conditions (weather and presence of pests and diseases) are uncontrollable. For some products, this would even be disastrous, because exposure to direct sunlight would ruin them. This is

particularly true for seeds for planting, which cannot tolerate temperatures above 40-45 °C, and for vegetables and fruits. For tubers and bulbs, it may be beneficial to leave them for some time (not too long) in the field at high temperatures. Seeds need to be dry for safe storage, so in periods of dry weather, drying could very well be done in the field.

3. During transportation and storage, some products are easily bruised or injured. This must be prevented by careful harvesting, but also by ensuring proper packaging and careful driving of the transport vehicle.
4. If seeds cannot be dried in the field, they have to be dried inside a building. If the weather is mostly dry, they can be dried in a well-ventilated building. Once dry, they can be kept in this ventilated building or packaged and stored elsewhere. If the weather is mostly humid, they have to be dried artificially by using a fan and a current of warm air. The temperature should not become too high because the seeds may then die.
5. The products are stored until consumed by the farmer and his or her family or until they are transported to the market. The optimal conditions may vary per product.
6. Refrigeration is suitable for some products, but for economic reasons, it is mostly used only with expensive products that come in small volumes. Some tropical fruits are injured by low temperatures.
7. Products that respire should not be stored airtight, so not in plastic, closed containers or warehouses without ventilation.
8. Products that do not breathe (dry seeds) can be stored in airtight containers or spaces.
9. Products that contain a lot of moisture must be stored in relatively humid conditions. These conditions are also favourable for the growth of fungi and bacteria, so care should be taken to store only products that are free from fungi and bacteria. Seeds that are still too wet to be stored under airtight conditions need to be stored in spaces with only very small holes to keep insects, rats and mice out, but on the other hand, also need good ventilation to further the drying process.
10. Fruits that produce ethylene gas during ripening cannot be stored together with many other fruits and vegetables, because ethylene gas causes ageing.
11. Regular (daily) inspection is important to detect product deterioration and attack by rodents and insects as early as possible.
12. If the volume of product harvested is greater than that needed for family consumption, part of the production could also be preserved to increase its shelf life.

3.1.4 Storage of Seeds/Grains, Roots, Tubers, Bulbs, Vegetables and Fruits

i. Storage of seeds/grains

Seeds are the natural means for a plant species to propagate and spread. They also enable the species to survive during the period between growing seasons when weather conditions are unsuitable to support plant growth. Plant seeds are thus built for survival. They consist of (Figure 3) an embryo, a store of food to enable the embryo to grow and a coat to protect the embryo and food reserve. Under suitable conditions, the embryo germinates and grows into a new plant. The growing embryo then exhausts the food reserve. Water is the most important factor that triggers the growth of the embryo. If seeds are dry, and as long as they remain dry, no life processes take place, and the seeds remain intact and viable. Whether seeds are used for planting or as a source of food, it is important to be able to store them for a period of at least several months.

Challenges in the storage of seeds/grains

The first challenge in the storage of seeds is to properly dry them. Drying seeds has a double purpose. In the first place, it nearly stops respiration. If seeds to be used for food continue to respire, they will lose nutritional value. Seeds for planting will lose the ability to germinate. However, if seeds are dry enough, they will not respire and can be kept in storage for quite a long time. Depending on the plant species, this period can vary from several months to more than a year. The second purpose of drying seeds is to prevent spoilage by bacteria and fungi. If seeds are too wet when put into storage, they provide an ideal food source for bacteria and fungi. The activity of these storage pests raises the temperature in the storage area, and within quite a short time the seeds will be spoiled, both by direct damage (rotting and feeding by insects and other animals) and by the destruction of the germination capacity through the high temperature. For storage of food grains, the moisture content should therefore be no more than 13 per cent, for pulses, it can be around 2 per cent higher. This is called the 'safe moisture content' because below this point the seeds will no longer support the growth of bacteria and fungi.

Seeds for planting can be stored longer if they are dried a few per cent more. Very dry legume seeds pose another problem though: they become very brittle and are easily damaged when handled. Assessing the moisture content of seeds is often one of the largest problems faced by small-scale seed producers. There is no accurate method to judge moisture other than by using a small electronic moisture meter.

Some experienced farmers and seed handlers can judge seed moisture content by biting the seed. If the seeds crack, rather than break, they are dry enough for storage. Another low-cost alternative is to use salt that has been sun-dried for a couple of days. The salt is mixed with the seeds in a clean, dry glass jar and shaken for a minute. If the salt sticks to the glass then the seeds probably contain more than 15 per cent moisture and should be dried further. If the salt does not stick then the seeds are dry enough to be put into storage. Some oil-containing seeds are especially at risk of being damaged by micro-organisms because some fungi and bacteria can grow on them even when they have a very low moisture content. For instance, groundnuts have to be dried to below 8 per cent moisture to prevent the growth of some fungi that produce substances (aflatoxins) that are toxic to people. Stored oilseeds can also become rancid (develop an unpleasant odour or flavour). Seeds are a preferred food source for several insects, rodents and birds. For that reason, seeds cannot be kept very long in the field after the harvest. Insects and rodents can also be notorious pests for stored seeds. The second challenge is therefore to prevent insects and rodents from entering the seed store. An even greater challenge is to do this without the use of pesticides. Many pesticides are also poisonous for humans and domestic animals. For seeds that are to be used for planting, a third challenge is to prevent them from being destroyed by too much heat. Temperatures during harvest, drying and storage should not exceed 40 °C for grains and 35 °C for pulses.

Practical operations preparatory for storage of seeds/grains

Harvesting time and method

Harvesting must not take place too early or too late. Too early means that high moisture content will make dry storage of the seeds impossible. Too late will result in losses through disease and insect infestation, birds, shattering or spoilage through the rain. Too late will also increase the brittleness of the seeds, which makes them more likely to break when the crop is handled. Because of the higher value of a seed crop, it can be worth the extra trouble to harvest a little early and dry the seed artificially. This will eliminate most of the dangers mentioned. When you investigate drying methods that have not been specifically designed for seed, bear in mind that too much heat is the surest way to kill the seed.

If you want to rely on field drying, you must have planned your planting time so that harvesting can take place in the dry season. In most crops, the seed reaches maturity a while before normal harvesting time. The grain has been filled, the embryo is complete, and all that happens from then on is the loss of water. We say that the seed is then *physiologically mature*. In theory, it can be harvested any time after this point, provided you are equipped to deal with the high moisture content. In most pulses, physiological maturity is reached when the pods start to change colour.

Drying seeds

Dry weather with some wind is ideal for drying seeds. Too-high drying temperatures cause the kernels of some grains to break and may kill the seed embryo. Therefore drying of most sowing seeds is best done at a maximum temperature of 35°C. Only cereals can withstand temperatures of 40-45 °C. That is why the seed for planting is not dried in full sunlight, but the shade. It is disastrous for dry seeds to become wet again. Therefore, seeds have to be dried indoors when harvested in a rainy period. If there is only an occasional shower, seeds might still be dried in the field.

Maize will have to be dried when the seeds are still on the cob. The reason is, that the seeds are still too wet to be threshed, and thus they must be dried before they can be threshed. Maize cobs are often dried in specific buildings. During this pre-storage drying period, and sometimes even before harvesting, the seeds may easily become infested with insects. This should be avoided by adequate pest management during the growing season. When the products have reached the safe moisture content, the stems and foliage can be removed and the pulses can be stored in containers that take up less space. Often they will be threshed first. Even if the product is still too moist, it can be stored, provided that it can dry further during storage.

The oil-containing groundnuts, soybeans and sesame are first dried in the field with the foliage still attached. They are dried to a moisture content of no less than 15 per cent. At a lower moisture content, too many seeds will be broken during further handling. And broken seeds will also increase the incidence of infection by fungi and invasion by insects. Afterwards, they are threshed or picked by hand. The moisture content of 15 per cent seems to be the most suitable for picking by hand and threshing with flails or simple stripping machines.

Threshing

Methods of threshing are more or less the same for all kinds of seeds. It takes place when the seeds have almost reached the desired moisture content. This may be when they are still in the field or after additional drying inside a building. There are few, if any, specific threshing methods for seed. We just have to ensure that the local standard method is used as gently as possible, to avoid breakage. Pulses are especially sensitive. Here the value of harvesting a little early will be especially noticeable, as a seed with slightly higher moisture content is easier to handle. However, too wet is not right either, since handling can then cause internal damage. Additional drying should take place after threshing, but before winnowing and cleaning.

Threshing can begin later in the day. The simplest way of threshing pulses for seed is by stuffing the pods in bags and hitting these with sticks. Do not trample pods or run vehicles over them, as that is likely to cause too much damage. The groundnuts are again an exception: first because they are better stored in the pod until planting time, and second, because for use as planting seed there is no good alternative to threshing (shelling) by hand.

Threshing of cereals for seed is done with the same methods as when harvested for food. If you have enough space and suitable storage facilities, maize seed can also be kept very well on the cob. Small quantities of cobs can be bundled and hung indoors, but for larger quantities, a crib must be built. The threshed seed will generally need to be cleaned of soil, stones, chaff and other pieces of plants, as well as insects and weed seeds. Smaller quantities can be cleaned by hand, through winnowing, sieving and/or sorting. But if you have large quantities of seed, this will soon become a job that will have to be mechanized. A wide range of machinery is available, from simple to very advanced.

Whether sorting by hand or by machine, pay special attention to weed seeds and to crop seeds that do not look healthy. This may include discoloured, broken, stained, shrivelled or malformed seeds, and seeds attacked by insects. Even though many of these may already be taken out during winnowing or sieving, visual inspection and if necessary the last hand sorting before putting the seed into storage must always be done. Groundnuts, soybeans and sesame are threshed when they have a moisture content of about 15 per cent. Alternatively, the pods are picked by hand. This decreases the number of broken seeds and thereby also the risk of fungal growth and possible building up of aflatoxins.

ii. Storage of roots, tubers and bulbs

Her, emphasis is on cassava, sweet potato, potato and yam, as they are mostly used as staple foods and need to be stored for several months to be available year-round. For practical reasons we bulbs such as onions are also included since they are usually stored for several months under similar conditions.

Tubers and bulbs have special requirements concerning storage because of their high moisture content (60-80 per cent when fresh). They must retain this high water content in storage. If they are dried like seeds, they would lose their structure.

Challenges in the storage of roots and tubers

The storage of roots, tubers and bulbs involves a particular challenge. On the one hand, drying out (or 'desiccation') should be avoided. On the other hand, too much humidity around the roots and tubers may cause rotting. Living tubers continue to respire (breathe) fairly intensively, and this increases with storage temperature. When high tuber temperatures are combined with airtight storage, plant tissue will die due to a lack of oxygen. For example, potatoes get black hearts. As the temperature of the product increases, better ventilation is therefore necessary.

During storage, chemical changes take place in the roots, tubers and bulbs which may influence their firmness and taste. Tubers of most species are dormant for a certain period, after which they start to sprout. This period varies with the crop variety and the storage temperature of the tubers. Yams can be stored for about four months at a normal temperature without sprouting, but potatoes start sprouting after five weeks at 15 °C. Also, tubers are often attacked by rodents during storage.

The keeping quality of tubers that are not cooled depends on the species. The keeping quality is longest for yam, then cocoyam and sweet potato, and it is shortest for cassava. The lower the temperature is, the lesser the likelihood of desiccation and rotting, provided the temperature does not fall below freezing. In other words: keeping the temperature low during storage is the best method. However, in practice, this is usually not feasible, since refrigeration equipment is unavailable or very expensive. The best alternative is to keep the storage room as cool as possible and well ventilated.

If ventilation can be regulated, for example by using a ventilator or adjustable ventilation vents (in a barn), the area should be ventilated during the coolest time (at night) and insulated during the hottest time of the day to trap the cool air. However, this kind of temperature regulation requires a thick-walled storage room. With natural ventilation, for example in huts, the temperature is difficult or impossible to regulate. The cooler the conditions (which will depend on, among other things, the season and altitude), the less ventilation is needed, but the chances of rotting and internal heating are higher. Yam, sweet potatoes and cassava should not be cooled below 12°C because they are damaged by low temperatures.

Practical operations preparatory for storage of roots, tubers and bulbs

Harvesting when needed

Certain varieties of yam, sweet potatoes and in particular cassava can be left in the ground during the dry season without harvesting. The quality remains reasonable, though often the tubers become more fibrous. Although this method seems very attractive, it has several disadvantages, including the following:

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

Short-season cassava varieties mature as early as 6 months after planting. They cannot be left in the ground for more than 9-11 months without serious deterioration. Long-season varieties take a year or more to mature. Sometimes they can be left in the ground for 3-4 years without serious deterioration. Unfortunately, the more attractive sweet cassava often belongs to the first group, while the less tasteful bitter variety tends to belong to the second group. Leaving cassava tubers in the ground and harvesting them when needed as food or feed is the best option to ‘store’ them.

Pre-harvest pruning

The shelf life of cassava roots is extended considerably by the pre-harvest pruning of the plants. Between 4 weeks to 1 week before the harvest, all the leaves are removed, leaving a stalk of approximately 20 cm in the ground. If a piece of the stalk is left attached to the roots during harvesting, the chances of rotting are less. Yam tubers are usually harvested all at once and subsequently stored. Leaving yams in the ground during the dry season may be done without appreciable loss of quality.

Preventing injuries

Rotting begins with wounds that are inflicted during harvesting and transport. Therefore harvesting should be done as carefully as possible, preferably with wooden tools. If the crop is planted in rows and ridges, the roots and tubers can be lifted if they are not too far apart.

The lifting tool should be able to pass easily underneath. More than 50 per cent of tubers are often damaged, but only about 5 per cent of the small ones. Damaged tubers should be consumed immediately or should be specially treated. Rubbing the damaged spots with sieved wood ashes, with lime or with chewed cola nuts and then drying them in the sun for 1 or 2 days heals the wounds and notably decreases the chance of rotting.

Curing of roots and tubers

To make the tubers more suitable for storage, they can undergo special treatment, called 'curing'. Generally, the tubers are stored under very warm (25-35 °C) and very humid (85-95 per cent relative humidity) conditions for several days. During this time a layer of cork, a few cell layers thick, is formed around the tubers. This layer greatly reduces the desiccation process and largely prevents infection by bacteria and fungi. Although the curing process is faster in full sunshine, it is better to protect the tubers against the sun with big leaves, because otherwise, the relative humidity around the tubers decreases rapidly and the strong heating of the tubers initiates processes that reduce the keeping quality. Cassava roots are cured for 4-7 days at a temperature of 30-35°C and relative humidity of 80-95 per cent. Wounds should be treated and left to dry. Sweet potatoes are cured for 5-7 days at about 30 °C and have a relative humidity of 85-90 per cent. The tubers can be left in the field in small heaps that are covered at night with straw or jute sacks if the temperature drops below 25 °C. Yam is cured for 4 days at 29-32°C and with a relative humidity of 90-95 per cent.

Satisfactory healing only occurs around deep wounds such as knife cuts. Bruised tubers with superficial wounds do not respond to curing. Such tubers can only be preserved by cutting off the bruised parts before curing. The curing of potatoes takes place for 5-8 days at much lower temperatures of 8-20°C with a relative humidity of approximately 90 per cent. Condensation of water on tubers must be prevented by ensuring only small temperature fluctuations.

Curing of bulbs

Bulbs are cured in a hot and well-ventilated environment. Contrary to the curing of tubers it is preferably done at low humidity. This dries out the neck and the two or three outer layers of scale leaves of the bulb. The outermost layer, which may be contaminated with soil, usually falls away easily when the bulbs are cured. The dry under-layer, with a more attractive appearance, then becomes visible.

Onions are considered cured when the neck is tight and the outer scales are dried until they rustle. This condition is reached when onions have lost 3-5 per cent of their weight.

If onions cannot be cured in the field, they can be collected in trays, which are then stacked in a warm, covered area with good ventilation. Curing in the shade improves bulb colour and significantly reduces losses during storage. In cool, damp climates, onions are stored in bulk in ventilated rooms. They are dried with air at 30°C blowing through the bulk. Onions can also be cured by tying the tops of the bulbs in bunches and hanging them on a horizontal pole in a well-ventilated shed. After curing the bulbs are graded before they go into storage. Thicknecked, injured and decayed bulbs are picked out by hand and discarded. Grading may be repeated after storage to get a better price on the market. The outer dry scales usually rub off during the grading process, giving the onions a better appearance. Proper sorting and grading reduce losses in storage.

iii. Storage of vegetables and fruits

Whereas seeds and root crops are often eaten year-round, vegetables and fruits are not always available and consumption changes with the seasons. See a detailed discussion on the storage of vegetables and fruits in Module 3 Unit 4.

3.1.5 Factors Affecting Storage of Farm Produce

The following factors affect the storage of any agricultural produce:

a. Quality of the product to be stored.
b. Environmental factors
c. Biological factors

a. **Quality of the product to be stored:** It is estimated that 9 to 16 per cent of the product is lost due to post-harvest problems during transportation and handling. Mechanical injury is a major cause of losses. Many of these injuries cannot be seen at the time that the product is packed and shipped, such as internal bruising in tomatoes. Other sources of loss include over-ripening, senescence, the growth of pathogens and the development of latent mechanical injuries. A grain for storage should have good characteristics, such as the following:

i. **High purity:** Before storage, the grain should be cleaned to remove contaminating seeds such as weed seeds, other crop seeds, and chaff. The quantity and type or source of impurity affect the usefulness of the product.

ii. **Good physical condition** (shape, size and colour): There should be no shrinkage, distortion, discolouration or heat damage. Discolouration or dullness in colour and shrivelling reduce the eye appeal.

iii. **No damage from insects**: Grain for storage should not have holes. Insect damage can reduce grain quality and income to the producer or processor.

iv. **Minimal mechanical damage**: Breakages, cracks and splits accelerate the deterioration of grain in storage. The soundness of grain is of paramount importance for good storage.

v. **High viability:** this is critical when the stored grain is intended for use as planting material.

vi. **Drying to safe moisture content**: Drying to safe moisture before storage reduces the incidence of moulds and the growth of other pathogens.

b. **Environmental factors:** The important environmental factors that affect crop storage are temperature, moisture, relative humidity, atmospheric composition and light. A detailed discussion on these factors is carried out under **"an** ideal environment for storage" in module 4.

c. **Biological factors:** Biological factors that cause deterioration on harvested produce are:

i. **Respiration:** Respiration is a basic process of all plant materials. It might simply be defined as the reverse of photosynthesis. It is a set of metabolic reactions taking place in the cells of organisms to convert biochemical energy from stored food (produced during photosynthesis, i.e. starch and sugar) into adenosine triphosphate (ATP) for growth, ripening etc. During respiration, plants take oxygen from the air and give off carbon dioxide, moisture, and heat. Respiration continues until the stored starch and sugar reserves are depleted and crops would age and die. Temperature dictates the speed of respiration and is the most important factor influencing the postharvest life of the given product. The oxygen in the surrounding environment is of utmost importance, while it is the primary gas used during respiration. Lowering the oxygen in the air lowers the respiration rate, but if there is not enough oxygen, and the, product goes into anaerobic fermentation and produces alcohols with abnormal flavours.

ii. **Transpiration:** Most fruits and vegetables contain between 80 and 95% water by weight. The loss of water in a vapour state from living tissues is known as transpiration. It causes shrivelling, wilting, softening, poorer texture, loss in weight, and lower quality. It can be reduced in storage by (1) raising the relative humidity, (2) reducing the air movements, (3) lowering the air temperature, (4) using protective coverage, i.e. waxing, and (5) protective packaging, i.e., polyethene film, modified atmosphere packaging etc.

iii. **Ethylene:** Ethylene gas (C_2H_4) is a colourless, odourless, natural hormone produced by some fruits (climacteric) and vegetables as they ripen and promotes additional ripening of produce exposed to it. This can lead to the premature ripening of produce in storage facilities. Ethylene is capable of stimulating many reactions within plants. It is involved in the normal ripening process in many fruits, such as apples and bananas. Ethylene can also have undesirable effects on fruits, i.e. premature ripening, skin damage etc. The presence of CO_2, lack of O_2, and low temperatures can inhibit ethylene production on fruits, while on the other hand ethylene production is higher at injured produce. Ethylene can also be produced artificially and used as an environmental factor to stimulate ripening. An important point here is that the plants which produce ethylene (e.g. apple) should not be stored with fruits, vegetables or flowers known to be sensitive to it (e.g. cabbage), as they may cause injuries, loss of quality, and reduce shelf life.

iv. **Postharvest diseases:** Stored products are subject to a variety of rots and decay caused by fungi or bacteria. The most known fungus are *Penicillium expansum*, *Botrytis cinerea*, *Alternaria alternata*, *Rhizopus stolonifer*, *Phytophthora infestans* and *Fusarium* spp and the bacteria are *Erwinia carotovora* and *Pseudomonas* spp. These diseases might cause light brown and soft spots on fruits and vegetables. Infection of diseases may start before or after harvest. When products are transferred to storage, infections continue to develop. Mechanical damages, wounds or bruises are known to be the common entry points for bacteria and fungi. To prevent postharvest diseases, careful monitoring and management of diseases need to be started during the growing period and continue in the storage. Preventing mechanical damage and harvesting the products during the cool times of the day are crucial points. Preharvest and postharvest application of suitable fungicides, bactericides might help manage disease problems.

SELF-ASSESSMENT EXERCISE

Answer true (T) or false (F)

	F	Stored products are subject to a variety of rots and decay caused by humans
T	F	*Ervinia carotovora* is a bacterium
T	F	Preharvest and postharvest application of suitable fungicides and bactericides cannot help in managing disease problems
T	F	Ethylene is capable of stimulating many reactions within plants

T	F	Too-high drying temperatures cause the kernels of some grains to break and may kill the seed embryo.
T	F	Vegetables and fruits are always available throughout the season
T	F	Respiration is an environmental factor that causes deterioration on harvested products
T	F	Drying to save moisture before storage reduces the incidence of moulds and the growth of other pathogens on stored agricultural products
T	F	With natural ventilation, for example in huts, the temperature is easy to regulate
T	F	If seeds to be used for food continue to respire, they will lose nutritional value.
T	F	The seed for planting can tolerate temperatures above 40-45°C
T	F	Bruised tubers with superficial wounds do not respond to curing
T	F	The shelf life of cassava roots is extended considerably by pre-harvest pruning of the plants
T	F	Dry weather with some wind is ideal for drying seeds

4.0 CONCLUSION

The factors that affect the storage of any agricultural products include the quality of the product to be stored, environmental factors and biological factors. These, together with factors that necessitate storage, were discussed in this unit.

5.0 SUMMARY

Farm produce is stored to ensure that food is available throughout the year at affordable prices, reduce to the barest minimum the amount of food spoilage caused by pests and disease attacks, preserve planting material for the next planting season, maintain or preserve the quality of food, ensure adequate supply of raw materials to industry for processing, make provision for large scale processing, ensure price control and regulation, optimize farmers' gain / empower farmers financially and take advantage of an export opportunity. Stored produce is affected by the quality of the products stored, environmental factors and biological factors.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. what factors affect agricultural produce in the store?
2. why is it necessary to store agricultural produce?
3. list and discuss the environmental factors that affect stored produce.
4. list and discuss the biological factors that affect stored produce
5. list six characteristics of grain for storage.

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UNIT 2 STRATEGIES FOR REDUCING POST-HARVEST LOSSES

CONTENTS

1.0 INTRODUCTION

The term "postharvest loss" refers to measurable quantitative and qualitative food loss in the postharvest system. Along with the renewed focus on investment in agriculture, there is an increasing interest in effective intervention for post-harvest loss reduction.

This unit discusses strategies of reducing post-harvest losses in cereal grains, strategies of reducing post-harvest losses in roots and tubers as well as strategies of reducing post-harvest losses in fruits and vegetables.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- know the strategies for reducing post-harvest losses in cereal grains, roots and tubers as well as fruits and vegetables.
- know the type of strategies to be adopted at different stages of the food system.

3.0 MAIN CONTENT

3.1 Strategies for Reducing Post-Harvest Losses

Some strategies for reducing postharvest losses are listed below:

3.3.1 Strategies of Reducing Post-Harvest Food Losses in Cereal Grains

Stage in the food system	Description and strategy
Harvesting	In tropical countries in general, most grains have a single annual harvesting season, although in bimodal rainfall areas there may be two harvests (e.g., Ghana and Uganda). African producers harvest grain crops once the grain reaches physiological maturity. At this stage, the grain is very susceptible to pest attacks. Poor farmers sometimes harvest crops too early due to food deficiency or the desperate need for cash. In this way, the food incurs a loss in nutritional and economic value and may get wasted if it is not suitable for consumption. Quality cannot be improved after harvest, only maintained; therefore, it is important to harvest at the proper maturity stage and peak quality.
Drying	Most farmers in Africa rely almost exclusively on the natural drying of crops by combining sunshine and movement of atmospheric air through the product; consequently, damp weather at harvest time can be a serious cause of postharvest losses. Grains should be dried in such a manner that damage to the grain is minimized and moisture levels are lower than those required to support mould growth during storage (usually below 13-15%). This is necessary to prevent further growth of fungal species that may be present on fresh grains. The harvested crop may be dried in the yard or a crib.
Threshing/shelling	For some grains, particularly millet and sorghum, threshing may be delayed for several months after harvest and the unthreshed crop stored in open cribs. In the case of maize, the grain may be stored on the cob with or without sheathing leaves for some months, or the cobs may be shelled and grain stored.
Winnow/cleaning	Usually done before storage or marketing if the grain is to be sold directly. For the majority of the smallholders, this process is done manually. It is relatively ineffective from a commercial perspective since grain purchased from smallholders frequently requires screening to

	remove stones, sand, and extraneous organic matter. There is little incentive for smallholders to provide well-cleaned grain for marketing; as a result, profits from sales are limited.
On-farm storage	Post-harvest losses at storage are associated with both poor storage conditions and lack of storage capacity. Stores must be constructed in such a way as to provide: -dry, well-vented conditions allowing further drying in case of limited opportunities for complete drying before storage; -protection from rain and drainage of groundwater; and -protection from entry of rodents and birds and minimum temperature fluctuations.

3.3.2 Strategies of Reducing Post-Harvest Food Losses in Roots and Tubers

Roots and tuber crops are still living organisms after they have been harvested and losses that occur during storage arise mainly from their physical and physiological conditions. The main causes of loss are associated with mechanical damage, physiological condition (maturity, respiration, water loss, sprouting), diseases and pests. To ensure effective storage of root and tuber crops, these major causative factors need to be properly understood and, where appropriate, be properly controlled, taking into account the socio-economic factors which prevail in the areas of production and marketing.

Stage in the food system	**Description and strategy**
Harvesting	It is the most important phase. Unless this operation is carried out with maximum efficiency, later prevention of food loss activities may be a waste of time. If, for example, roots and tubers are bruised or otherwise damaged during harvesting, consideration of improved handling or packaging is not likely to be worthwhile, since an early infestation with moulds and viruses will occur and rotting will have started. If harvesting operations are correctly undertaken there is greater scope for the later introduction of improved methods. Provision of the proper tools and equipment for harvesting and training workers in their correct use should be a priority prevention of food loss activity.
Handling	The skin of roots and tubers is an effective barrier to most of the opportunistic bacteria and fungi that cause the rotting of the tissues. Breaking of the skin

	also stimulates physiological deterioration and dehydration. Careful digging and movement of roots and tubers significantly reduce post-harvest losses.
Packing	Packing of the roots is usually done in the field. Farmers commonly pack the roots and strategically place the large roots at the top of the bag to quickly attract the buyer at first sight. Packing should minimize deterioration of the roots within the container and cushion against impact and compression. During packing in the field care must be taken to minimise physical damage that results from impact bruises due to stacking and overfilling of bags, abrasion or vibration bruises due to root movement against each other. Therefore packages should be neither loose (to avoid vibration bruising during transport) nor overfilled and should provide good aeration.
Transportation	Temperature management is critical during long-distance transport, so loads must be stacked to enable proper air circulation to carry away the heat from the produce itself as well as incoming heat from the atmosphere and off the road. In many developing countries traditional baskets and various types of trays or buckets are used for transporting produce to the house or village markets. These are usually of low cost, made from readily available material and serve the purpose of transport over short distances. But, they have many disadvantages in large loads carried over long distances (i.e. they are difficult to clean when contaminated with decay organisms). However, packaging can be a major item of expense in produce marketing, especially in developing countries where packaging industries are not well developed. The selection of suitable containers for commercial-scale marketing requires very careful consideration. Among the various types of packaging material that are available: natural and synthetic fibre sacks and bags as well as moulded plastic boxes seem to be more suitable and have greater promise for packaging roots and tubers and their transport to distant markets.
Storage	The following three things must be done to ensure the successful storage of fresh roots and tubers. i) Carefully select only top-quality roots and tubers without any signs of handling or pest or disease

	damage for storage; ii) keep them in specially designed stores and iii) check the stores at regular intervals. Many farmers do not routinely store fresh roots and tubers, but leave them in the ground until required. It is possible to store fresh roots successfully in specially constructed pits or mounds, or clamp stores. For example, when storing potatoes, a field storage clamp is a low-cost technology that can be designed using locally available materials for ventilation and insulation.
Processing	Root and tuber crops (cassava, sweet potato, yam etc) are both important household food security and income-generating crops in many developing countries. Overcoming the perishability of the crops, improving marketing, enhancing nutritional value and adding economic value through processing are the main strategic areas for reducing postharvest losses. The various processing techniques are listed as follows: 1. peeling and washing, 2. grating, 3. pressing/fermentation, 4. sieving, 5. frying/drying. An important aspect of processing is that it is often intended to prolong the preservation period of a product under ambient conditions. The most appropriate products in this respect are dehydrated root and tubers products such as potato products (starch and flakes). Besides permitting better preservation, the drying and processing of root and tubers into dried chips and flour offers other advantages such as facilitating transport and increased shelf life and creating new opportunities for the farmer such as new markets and new sources of income. Metal storage bins or water tanks made from smooth or corrugated galvanized metal sheets are used for storing dried products. Dehydration or sun drying is the simplest and lowest cost method of preservation and should be more widely promoted and used in developing countries because it converts a perishable commodity into a stable item with long storage life.

3.3.3 Strategies of Reducing Post-Harvest Food Losses in Fruits and Vegetables

It is important to highlight that; some varieties of the same crop store better than others. Therefore,

Stage in the food system	**Description and strategy**
Harvesting	Harvesting should be carried out as carefully as possible to minimize mechanical injury such as scratches, punctures and bruises to the crop. The time of the day when harvesting is done also affects product quality and shelf-life. In general, harvesting during the coolest time of the day (early morning) is desirable; the product is not exposed to the heat of the sun and the work efficiency of the harvesters is higher. If harvesting during the hotter part of the day cannot be avoided, the product should be kept shaded in the field to minimize product weight loss and wilting.
Handling	Mechanical injury provides sites for pest attack and increases physiological losses. Therefore, avoid mechanical injury to the crop while handling. Because of their soft texture, all horticultural products (fruits and vegetables) should be handled gently to minimize bruising and breaking of the skin. The skin of horticultural products is an effective barrier to most opportunistic bacteria and fungi that cause the rotting of the tissues. Breaking of the skin also stimulates physiological deterioration and dehydration. Reducing the number of times the commodity is handled reduces the extent of mechanical damage.
Sorting and cleaning	Systematic sorting or grading coupled with appropriate packaging and storage, will extend shelf life, maintain wholesomeness, freshness, and quality, and substantially reduce losses and marketing costs. Sorting is done to separate poor produce from good product, and further classify the good product based on other quality parameters like the size.
Transportation	Proper packing is essential to maintain the freshness of the leafy vegetable. Packaging should be designed to prevent premature deterioration in product quality, in addition to serving as a handling unit. Use clean, smooth and ventilated

	containers for packaging. This is a very important factor in cutting down losses in these crops during harvesting, transportation, marketing and storage. Use containers that are appropriate for the crop.
Storage	Only crops with high initial quality can be stored successfully; it is, therefore, essential to ensure that only crops of the highest quality (mature, undamaged) are stored. Shelf life can be extended by maintaining a commodity at its optimal temperature, relative humidity and environmental conditions.
Processing	Processing is an important value-added activity that stabilizes and diversifies food supplies and creates employment and income opportunities. It can minimize the high perishability problem of leafy vegetables. Processed products are also more stable, have improved digestibility, and permit a better diet diversity, giving consumers access to a wider choice of products and a wider range of vitamins and minerals. Processing technologies include drying, salting, fermenting, and pickling.

SELF-ASSESSMENT EXERCISE

In tropical countries in general, most grains have a single annual harvesting season. True/False

- Shelf life can be extended by maintaining a commodity at its optimal temperature, relative humidity and environmental conditions. True/False
- Mechanical injury provides sites for pest attack and increases physiological losses. True/False
- The time of the day when harvesting is done does not affect product quality and shelf-life. True/False
- Dehydration or sun drying is the simplest and lowest cost method of preservation. True/False
- Breaking of the skin in root and tuber crops does not stimulate physiological deterioration and dehydration. True/False

2. List the processing techniques in root and tuber crops.
3. What is postharvest loss?

4.0 CONCLUSION

To reduce food loss and to achieve maximum shelf-life, only varieties known to store well should be stored, and the strategies discussed in this unit should be adhered to.

5.0 SUMMARY

Measurable quantitative and qualitative food losses are encountered in the postharvest system. This system comprises interconnected activities from the time of harvest through crop processing, marketing and food preparation, to the final decision by the consumer to eat or discard the food.

Nowadays, interventions in post-harvest loss reduction are seen as an important component of the efforts of many agencies to reduce food insecurity.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

List the strategies of reducing post-harvest food losses in:

1. Cereal grains
2. Roots and tubers
3. Fruits and vegetables

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UNIT 3 FUNDAMENTALS AND PRINCIPLES OF CROP PRODUCTS PROCESSING AND STORAGE

CONTENTS

1.0 INTRODUCTION

Agricultural processing may be defined as an activity that is performed to maintain or improve the quality or to change the form or characteristics of the agricultural product. Processing operations are undertaken to add value to agricultural materials after their production. The main purpose of agricultural processing is to minimize the qualitative and quantitative deterioration of the material after harvest. High post-harvest food losses, arising largely from limited food preservation capacity, are a major factor constraining food and nutrition security in the developing countries of West Africa, where seasonal food shortages and nutritional deficiency diseases are still a major concern. Simple, low-cost, traditional food processing techniques are the bedrock of small-scale food processing enterprises that are crucial to rural development in West Africa. It is estimated that about 50% of perishable food commodities including fruits, vegetables, roots and tubers and about 30% of food grains including maize, sorghum, millet, rice and cowpeas are lost after harvest in West Africa. Ineffective or inappropriate food processing technologies, careless harvesting and inefficient post-harvest 122 handling practices, bad roads, moribund rail systems, bad market practices and inadequate or complete lack of storage facilities, packing houses and market infrastructures are some of the factors responsible for high post-harvest food losses in West African countries.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- define food processing
- describe the basic principles of agricultural processing

- describe the basic principles of agricultural storage
- Describe the different types of agricultural processing
- give reasons for food processing
- state the dos and don’ts of crop storage.

3.0 MAIN CONTENT

3.1 Fundamentals and Principles of Crop Products Processing and Storage

3.3.1 Fundamentals and Principles of Crop Products Processing Reasons for Food Processing

a) To improve its digestibility, making it easier for the body to break down the food while it is in the stomach.
b) To improve its sanitary quality, making it safer to eat by killing harmful micro-organisms.
c) To create desirable flavours which are pleasant to the taste.
d) To preserve it, so allowing it to be kept over a period saving time and energy.

Principles of Agricultural Processing
Food processing includes food preparation (which makes food items ready for immediate consumption) and food preservation (which preserves food items for future use). Food processing may sometimes cause certain desirable food qualities to be lost. Food preservation may be either short or long term. Short term preservation may apply to horticultural commodities that are consumed relatively soon after harvest. For them, the best preservation techniques involve keeping the product alive and respiring. Shorter preservation does not involve the destruction of microorganisms or enzymes, deteriorative reactions will therefore proceed, often at a faster rate due to the stresses imparted during harvesting and handling operations.

Long term preservations encompass inactivation or control of microorganisms and enzymes and reduction or elimination of chemical reactions that cause food deterioration. Microorganisms may be controlled through the use of heat, cold, dehydration, acid, sugar, salt, smoke, atmospheric composition and radiations. Mild heat treatments in the range of 82ºC to 93ºC are commonly used to kill bacteria in low acid food but to ensure spore destruction; temperatures of 121ºC wet heat for 15 minutes or longer are required. Refrigeration and freezing slow microbial growth and may kill a small fraction of microorganisms present in or on a fruit or vegetable, but they do not kill all bacteria. If all of the water in a product exists in a solid-state, growth of microorganisms will be prevented, but growth would resume at the same or perhaps at an even more rapid rate when thawed. Dehydration serves to remove water required for growth from microbial cells and preserve horticultural crops against microbial deterioration. Similarly, sugar and salts act as preservatives because they cause osmotic dehydration of microbial cells and eventual death. Control of moisture or RH of the storage environment is an important consideration in terms of desired maintenance of horticultural crop life and undesired preservation of microorganisms.

Types of Agricultural Processing
Agricultural processing may be defined as an activity, which is performed to maintain or improve the quality or to change the form or characteristics of the agricultural product. Processing operations are undertaken to add value to agricultural materials after their production. The main purpose of agricultural processing is to minimize the qualitative and quantitative deterioration of the material after harvest. Different types of food processing can be categorized into:

Primary processing: Purification of raw materials by removing foreign matter, immature grain and then making the raw material eligible for processing by grading in different lots or conversion of raw material into the form suitable for secondary processing.

Secondary processing: Processing of primary processed raw material into a product that is suitable for food uses or consumption after cooking, roasting, frying etc.

Tertiary processing: Conversion of secondarily processed material into ready-to-eat form.

Food items are marketed in different forms as raw, primarily processed, secondarily processed and tertiary processed. The farmers, in general, prefer to sell their agricultural produce immediately after harvest leaving it apart for their consumption and seed purposes. The food processing sector has gained importance due to consumer’s preferences for ready to cook (RTC) and ready to eat (RTE) foods, besides increased demand for snack foods and beverages.

3.3.3.2 Fundamentals and Principles of Crop Products Storage Grain Storage Principles

a. Conditions of the Grains

i. Only clean, unbroken kernels should be selected for storage.
ii. The grain should be dry.
iii. The grain should be cool when it is put into storage.

b. Climatic Conditions

Grain stores best in weather that is dry and cool. Unfortunately, the weather is not always dry and cool. During the serious rainy season, even well-dried grain can become wet again if it is exposed to very wet air or rain. Since grain must be stored during all kinds of weather the type of storage method chosen must protect the grain from the worst possible weather conditions.

c. Store Conditions

A grain store must perform one task: the store must protect the grain from its natural enemies (moulds and fungi, insects, rats, birds, and other animals). To do this a grain store should have the following properties: i. The store must be dry, ii. The store should be cool, iii. The store should keep out the sun, iv. The store should be clean, v. The store should have no holes or cracks in the roof, walls, or floor, and vi. The store might need to be treated with insecticide.

Store location: Site stores away from any potential source of the infestation and away from growing crops. Grain and tuber moths are good flyers and adults from infested stores often infest growing crops in the field. Separating stores from fields may therefore help to reduce the risk of attack.

3.3.3 Don'ts and Dos for Storage of Fresh Produce

1. Store only high quality produce, free of damage, decay and proper maturity (not overripe or under mature).
2. Know the requirements for the commodities you want to put into storage, and follow recommendations for proper temperature, relative humidity and ventilation. Never store carrot with apple or any fruit releases ethylene gas because carrot is very sensitive to ethylene and develops bitterness due to the formation of a compound called iso-coumarin.
3. Avoid lower than recommended temperatures in storage, because many commodities are susceptible to low-temperature injury called freezing or chilling.
4. Do not overload storage rooms or stack boxes tightly; it will hinder air movement through all boxes. Air follows the same path or easiest path if not blocked.
5. Boxes should be stored on perforated wooden racks specially designed for air movement.
6. Provide adequate ventilation in the storage room by keeping little space between two stack lines. Boxes should not be stored on the passage kept for the movement of staff and labourers.
7. Storage rooms should be protected from rodents by keeping the immediate outdoor area clean, and free from trash and weeds.

8. Containers/Boxes must be well ventilated and strong enough to stand stacking. Do not stack boxes beyond their stacking strength.
9. Monitor temperature in the storage room by placing thermometers at different locations.
10. Don’t store onion or garlic in high humidity environments.
11. Control Insect/Pest/rodents population inside the store.
12. Check your produce at regular intervals for any sign of damage due to insect/pest/water loss, ripening, shrivelling, etc.
13. Remove damaged or diseased produce to prevent the spread of pathogens.
14. Always, handle produce gently and never store produce unless it is of the best quality.
15. Damaged produce will lose water faster and have higher decay rates in storage as compared to undamaged produce and must be removed.

It is advisable not to store different crops together in one room of any cold store. But practically, it is very difficult to maintain and in some cases, it is unavoidable, particularly at distribution or retail levels. A strategy widely practised is to set cold chambers at an average of around 2–5°C and 90–95 per cent relative humidity irrespective of specific requirement. Frequent opening and closing of cold store chamber for product loading and unloading cause an increase in temperature and decrease in relative humidity. Therefore, it is advisable for specific chambers.

SELF-ASSESSMENT EXERCISE

1. The following are reasons for food processing, except:
    a) To improve its digestibility, making it easier for the body to break down the food while it is in the stomach.
    b) To improve its sanitary quality, making it safer to eat by killing harmful micro-organisms.
    c) To improve seed viability.
    d) To create desirable flavours which are pleasant to the taste.
    e) To preserve it, so allowing it to be kept over a period saving time and energy.

2. Which of the following is not among the “don’ts” of crop storage?
    a) Avoid lower than recommended temperatures in storage, because many commodities are susceptible to low-temperature injury called freezing or chilling.
    b) Do not overload storage rooms or stack boxes tightly; as it will hinder air movement through all boxes.

c) Do not protect storage rooms from rodents.
d) Don't store onion or garlic in high humidity environments.

3. Which of the following is not among the "dos" of crop storage?
 a) Store only high quality produce, free of damage, decay and proper maturity (not overripe or under mature).
 b) Know the requirements for the commodities you want to put into storage, and follow recommendations for proper temperature, relative humidity and ventilation. Never store carrot with apple or any fruit releases ethylene gas because carrot is very sensitive to ethylene and develops bitterness due to the formation of a compound called iso-coumarin.
 c) Tolerate lower than recommended temperatures in store
 d) Provide adequate ventilation in the storage room by keeping little space between two stack lines. Boxes should not be stored on the passage kept for the movement of staff and labourers.
 e) Storage rooms should be protected from rodents by keeping the immediate outdoor area clean, and free from trash and weeds.

4.0 CONCLUSION

Agricultural processing may be defined as an activity, which is performed to maintain or improve the quality or to change the form or characteristics of the agricultural product. Processing operations are undertaken to add value to agricultural materials after their production. The storage requirements of the range of crops produced are extremely varied. For durables, such as cereal grains, the requirements are comparatively simple, while the physiological characteristics of fresh fruit, vegetables and root crops demand a broader range of technical interactions. Whether the durables or fresh fruits, vegetables or root and tuber crops, observance of the dos and don'ts of crop storage is necessary.

5.0 SUMMARY

Food items are marketed in different forms as raw, primarily processed, secondarily processed or tertiary processed. The farmers, in general, prefer to sell their agricultural produce immediately after harvest leaving it apart for their consumption and seed purposes. The food processing sector has gained importance due to consumers' preferences for ready to cook (RTC) and ready to eat (RTE) foods, besides increased demand for snack foods and beverages. Store conditions, climatic conditions and the conditions of the products to be stored are all very important considerations in agricultural produce storage.

6.0 TUTOR-MARKED ASSESSMENT

1. Write short notes on primary, secondary and tertiary food processing.
2. List three reasons for processing food.
3. What are the dos and don’ts of crop storage?
4. Write short notes on the Characteristics of a store for grain storage.

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UNIT 4 FRESH STORAGE OF FRUITS AND VEGETABLES

CONTENTS

1.0 INTRODUCTION

The marketable life of most fresh fruits and vegetables can be extended by prompt storage in an environment that maintains product quality. The desired environment can be obtained in facilities where (1) temperature, (2) air circulation, (3) relative humidity, and sometimes (3) atmospheric composition can be controlled.

Storage rooms can be grouped accordingly as (1) those that require refrigeration and (2) those that do not require refrigeration.

Storage rooms and methods not requiring refrigeration include: in situ, sand, coir, pits, clamps, windbreaks, cellars, barns, evaporative cooling, and night ventilation. It is not always possible to consume or sell all fruits and vegetables while they are still fresh. In this case, part of the harvest may be processed to preserve it for a longer period.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- know the means that are commonly used to prevent spoilage of fruits and vegetables
- know the procedures for fruit and vegetable preservation
- describe a way of extending the shelf life of harvested fruits and vegetables.

3.0 MAIN CONTENT

3.1 Fresh Storage of Fruits and Vegetables

Means that are commonly used to prevent spoilage of fruits must include care to prevent cutting or bruising of the fruit during picking or handling, refrigeration to minimize the growth of micro-organisms and reduce enzyme activity; packaging or storage to control respiration rate and ripening, and use of preservatives to kill micro-organisms on the fruit. Storing vegetables the right way will keep them fresh and safe to eat. Some fruits and vegetables need to be stored in the refrigerator, others need to ripen before being placed in the refrigerator, and others are best stored at room temperature or in a cool dry place.

Freezing vegetables is a fast and easy way to preserve nutrients and enjoy their taste for a long time. Most vegetables need to be blanched before they are frozen, blanching entails boiling whole or cut pieces for 1-2 minutes and then immediately placing them in ice-cold water to stop the cooking process. This will keep your vegetable from getting freeze burn. Frozen vegetables can keep up to one year. Freezing is not recommended for eggplant, lettuce greens, potatoes (other than mashed) and sweet potatoes. Squash and root vegetables should be stored in a cool, dark, dry spot outside the freeze. Garlic, onions, potatoes, sweet potatoes, yams and pumpkins can also be stored this way. For tomatoes, store them at room temperature away from direct sunlight. This will help them ripen evenly. Once they are ripe they can be placed in the freeze.

Procedures for fruit and vegetable preservation
The Procedures for fruit and vegetable preservation are summarized in Table 3.1.

Table 3.1: Summary of procedures for fruit and vegetable preservation

Procedures	Practical applications
Fresh storage	Fruits, vegetables
Cold storage	Fruits, vegetables
Freezing	Fruits, vegetables
Drying/dehydration	Fruits, vegetables
Concentration	Fruit and vegetable juices
Chemical preservation	Fruit semi-processed
Preservation with sugar	Fruit products/preserves
Pasteurization	Fruit and vegetable juices
Sterilization	Fruits, vegetables

Sterilizing filtration	Fruit juices
Irradiation	Fruits, vegetables

Note:

- Some of these preservation procedures are applied only to one or some categories of foods while others can be used across the board and thus have a wider application (cold storage, freezing, drying/dehydration, sterilization, etc.)
- Some guarantee food preservation on their own while others require combination with other procedures, either as principal or as auxiliary processes to assure preservation (for example smoking has to be preceded by salting).

Combined preservation procedures: In practice preservation procedures aim at avoiding microbiological and biochemical deterioration which are the principal forms of deterioration. Even with all recent progress achieved in this field, no single one of these technological procedures applied alone can be considered wholly satisfactory from a microbiological, physic-chemical and organoleptic point of view, even if to a great extent the food value is assured.

Preservation by drying/dehydration

The technique of drying is probably the oldest method of food preservation practised by mankind. The removal of moisture prevents the growth and reproduction of micro-organisms causing decay and minimizes many of the moisture mediated deterioration reactions.

It brings about a substantial reduction in weight and volume thereby minimizing packing, storage and transportation costs and enable storability of the product under ambient temperatures. The sharp rise in energy costs has promoted a dramatic upsurge in interest in drying worldwide over the last decade.

To assure products of high quality at a reasonable cost, dehydration must occur fairly rapidly. Four main factors affect the rate and total drying time:

- the properties of the products, especially particle size and geometry
- the geometrical arrangement of the products concerning heat transfer medium (drying air)
- the physical properties of drying medium/ environment
- the characteristics of the drying equipment

Drying techniques
Several types of dryers and drying methods, each better suited for a particular situation, are commercially used to remove moisture from a wide variety of food products including fruit and vegetables. There are three basic types of drying processes: sun drying and solar drying, atmospheric drying and sub-atmospheric dehydration.

Factors on which the selection of a particular dryer/drying method depends include:

- form of raw material and its properties;
- desired physical form and characteristics of the dried product;
- necessary operating conditions;
- cost of operation

Fruit and vegetable natural drying - sun and solar drying
Surplus production of crops may be preserved by natural drying for use until the next crop can be grown and harvested. Natural dried products can also be transported cheaply for distribution to areas where there are permanent shortages of fruit and vegetables. The methods of producing sun and solar dried fruit and vegetables described here are simple to carry out and inexpensive. They can be easily employed by growers, farmers, cooperatives, etc.

The best time to preserve fruits and vegetables is when there is a surplus of the product and when it is difficult to transport fresh materials to other markets. This is especially true for crops which are very easily damaged in transport and which stay in good condition for a very short time. Preservation extends the storage (shelf) life of perishable foods so that they can be available throughout the year despite their short harvesting season.

Sun and solar drying of fruits and vegetables is a cheap method of preservation because it uses the natural resource/ source of heat: sunlight. This method can be used on a commercial scale as well at the village level provided that the climate is hot, relatively dry and free of rainfall during and immediately after the normal harvesting period. The fresh crop should be of good quality and as ripe (mature) as it would need to be if it was going to be used fresh. Poor quality products cannot be used for natural drying.

Dried fruit and vegetables have certain advantages over those preserved by other methods.

1. They are lighter in weight than their corresponding fresh produce and,
2. They do not require refrigerated storage.

However, if they are kept at high temperatures and have a high moisture content they will turn brown after relatively short periods of storage.

Note that different lots at various stages of maturity (ripeness) must not be mixed; this would result in a poor dried product. Some varieties of fruit and vegetables are better for natural drying than others.

Damaged parts which have been attacked by insects, rodents, diseases, etc. and parts that have been discoloured or have a bad appearance or colour, must be removed. Before trimming and cutting, most fruit and vegetables must be washed in clean water. Onions are washed after they have been peeled.

Trimming includes the selection of the parts which are to be dried, cutting off and disposing of all unwanted material.

It is very important to have all slices/parts in one drying lot of the same thickness/size; the actual thickness will depend on the kind of material. Uneven slices or different sizes dry at different rates and this result in a poor-quality end product. Onions and root crops are sliced with a hand slicer or vegetable cutter; bananas, tomatoes and other vegetables or fruit are sliced with stainless-steel knives.

As a general rule plums, grapes, figs, dates are dried as whole fruits without cutting/slicing. Some fruit and vegetables, in particular bananas, apples and potatoes, go brown very quickly when left in the air after peeling or slicing; this discolouration is due to an active enzyme called phenoloxidase. To prevent the slices from going brown they must be kept under water until drying can be started. Salt or sulphites in solution give better protection. However, whichever method is used, further processing should follow as soon as possible after cutting or slicing.

Blanching - exposing fruit and vegetable to shot water as a pre-treatment before drying. It has the following advantages:

- it helps clean the material and reduce the number of micro-organisms present on the surface;
- it preserves the natural colour in the dried products; for example, the carotenoid (orange and yellow) pigments dissolve in small intracellular oil drops during blanching and in this way, they are protected from oxidative breakdown during drying;
- It shortens the soaking and/or cooking time during reconstitution.
  During hot water blanching, some soluble constituents are leached out: water-soluble flavours, vitamins (vitamin C) and sugars. With potatoes this may be an advantage as leaching out of sugars makes the potatoes less prone to turning brown. Blanching is a delicate processing step; time, temperature and other

conditions must be carefully monitored. A suitable water-blanching method in traditional processing is as follows:

- the sliced material is placed on a square piece of clean cloth; the corners of the cloth are tied together;
- a stick is put through the tied corners of the cloth;
- The cloth is dipped into a pan containing boiling water and the stick rests across the top of the pan thus providing support for the cloth bag.

The average blanching time is 6 minutes. The start of blanching has to be timed from the moment the water starts to boil again after the cloth bag has been dipped into the pan. While the material is being blanched the cloth bag should be raised and lowered in the water so that the material is heated evenly.

When the blanching time is completed the cloth bag and its content should be dipped into cold water to prevent over-blanching. If products are over-blanched (boiled for too long) they will stick together on the drying trays and they are likely to have a poor flavour.

Green beans, carrots, okra, turnip and cabbage should always be blanched. The producer can choose whether or not potatoes need blanching. Blanching is not needed for onions, leeks, tomatoes and sweet peppers. Tomatoes are dipped into hot water for one minute when they need to be peeled but this is not blanching. As a rule, fruit is not blanched.

Use of preservatives: Preservatives are used to improve the colour and keeping qualities of the final product for some fruits and vegetables. Preservatives include items such as sulphur dioxide, ascorbic acid, citric acid, salt and sugar and can either be simple or compound solutions.

Treatment with preservatives takes place after blanching or, when blanching is not needed, after slicing. In traditional, simple processing the method recommended is:

- Put enough preservative solution to cover the cloth bag into a container/pan.
- Dip the bag containing the product into the preservative solution for the amount of time specified.
- Remove the bag and put it on a clean tray while the liquid drains out. The liquid which drains out must not go back into the preservative solution because it would weaken the solution.

Care must be taken after each dip to refill the container to the original level with a fresh preservative solution of the correct strength. After five lots of material have been dipped, the remaining solution is thrown away; i.e. a fresh lot of preservative solution is needed for every 5 lots of material. The composition and strength of the preservative solution vary for different fruit and vegetables. The strength of sulphur dioxide is expressed as "parts per million" (ppm). 1.5 grams of sodium metabisulphite in one litre of water gives 1000 ppm of sulphur dioxide.

Sodium bicarbonate is added to the blanching water when okra, green peas and some other green vegetables are blanched. The chemical raises the pH of the blanching water and prevents the fresh green colour of chlorophyll from being changed into pheophytin which is unattractive brownish-green.

The preservative solutions in the fruit and vegetable pre-treatment can only be used in enamel, plastic or stainless-steel containers; never use ordinary metal containers because solutions will corrode them. As a general rule, preservatives are not used for treating onions, garlic, leeks, chillies and herbs.

Osmotic dehydration: In osmotic dehydration, the prepared fresh material is soaked in a heavy (thick liquid sugar solution) and/or a strong salt solution and then the material is sun or solar dried. During osmotic treatment, the material loses some of its moisture. The syrup or salt solution has a protective effect on colour, flavour and texture.

This protective effect remains throughout the drying process and makes it possible to produce dried products of high quality. This process makes little use of sulphur dioxide.

Note that the main problems for sun drying are dust, rain and cloudy weather. Therefore, drying areas should be dust-free and whenever there is a threat of dust, storm or rain, the drying trays should be stacked together and placed undercover.

To produce dust-free and hygienically clean products, fruit and vegetable material should be dried well above ground level so that they are not contaminated by dust, insects, livestock or people.

Shade drying: Shade drying is carried out for products that can lose their colour and/or turn brown if put in direct sunlight. Products that have naturally vivid colours like herbs, green and red sweet peppers, chillies, green beans and okra give a more attractive end-product when they are dried in the shade.

The principles for shade drying are the same as for sun drying. The material to be dried requires full air circulation. Therefore, shade drying is carried out under a roof or thatch which has open sides; it cannot be done either inside conventional buildings with sidewalls or in compounds sheltered from the wind. Under dry conditions when there is a good circulation of air, shade drying takes little more time than is normally required for drying in full sunlight.

b. Preservation by concentration

Foods are concentrated for many of the same reasons that they are dehydrated. Concentration can be a form of preservation but this is true only for some foods. Concentration reduces weight and volume and results in immediate economic advantages.

Nearly all liquid foods which are dehydrated are concentrated before they are dried. This is because, in the early stages of water removal, moisture can be more economically removed in highly efficient evaporators than in dehydration equipment. Further, increased viscosity from concentration often is needed to prevent liquids from running off drying surfaces or to facilitate foaming or puffing.

Foods are also concentrated because the concentrated forms have become desirable components of diet in their own right. Thus, fruit juices plus sugar with concentration becomes jelly. The more common concentrated fruit and vegetable products include items as fruit and vegetable juices and nectars, jams and jellies, tomato paste, many types of fruit purées used by bakers, candy makers and other food manufacturers.

Aspects of preservation by concentration

Level of water: The level of water in virtually all concentrated foods is in itself more than enough to permit microbial growth. Yet while many concentrated foods such as non-acid fruit and vegetable purées may quickly undergo microbial spoilage unless additionally processed, such items as sugar syrups, jellies and jams are relatively "immune" to spoilage; the difference, of course, is in what is dissolved in the remaining water and what osmotic concentration is reached. Sugar and salt in concentrated solutions have high osmotic pressure. When these are sufficient to draw water from microbial cells or prevent normal diffusion of water into these cells, a preservative condition exists.

The critical concentration of sugar in water to prevent microbial growth will vary depending upon the type of micro-organisms and the presence of other food constituents, but usually, 70% sucrose in solution will stop the growth of all micro-organisms in foods. Less than this concentration may be effective but for short periods unless the foods contain acid or they are refrigerated.

Salt becomes a preservative when its concentration is increased and levels of about 18% to 25% in solution generally will prevent all growth of micro-organisms in foods. Except in the case of certain briny condiments, however, this level is rarely tolerated in foods. Removal of water by concentration also increases the level of food acids in the solution (particularly significant in concentrated fruit juices).

Reduced weight and volume by concentration: While the preservation effects of food concentration are important, the main reason for most food concentrations is to reduce food weight and bulk. Tomato pulp (which is ground tomato minus the skins and seeds) has a solids content of only 6 % and so a 3.785 litre can contain only 227 g of tomato solids.

Concentrated to 32% solids, the same can would contain 1.21 kg of tomato solids. For a manufacturer needing tomato solids such as a producer of soups or canned spaghetti the saving from concentration is enormous in cans, transportation costs, warehousing costs and handling costs throughout his operation.

Methods of concentration

a. Solar concentration. Here water is evaporated with solar energy.
b. Open Kettles. Some foods can be satisfactorily concentrated in open kettles that are heated by steam. High temperatures and long concentration times should be avoided to reduce or eliminate damage.

Others are:

c. Use of Flash evaporators.
d. Of Use Thin-film Evaporators.
e. Use of Vacuum evaporators
f. Freeze Concentration.
g. Ultrafiltration and Reverse Osmosis.

Changes from concentration

Obviously, concentration that exposes food to 100° C or higher temperatures for prolonged periods can cause major changes in organoleptic and nutritional properties. Cooked foods and darkening of colour are two of the more common heat-induced results that must be kept under control during a well-designed process with an efficient evaporator that is still "safe".

Microbial destruction is another type of change that may occur during concentration and will be largely dependent upon temperature. Concentration at a temperature of 100 °C or slightly above will kill many micro-organisms but cannot be depended on to destroy bacterial spores. When the food contains acid, such as fruit juices, the kill will be greater but again sterility is unlikely.

On the other hand, when concentration is done under vacuum many bacterial types not only survive the low temperatures but multiply in the concentrating equipment. It is, therefore, necessary to stop frequently and sanitize low-temperature evaporators and where sterile concentrated foods are required, to resort to an additional preservation treatment.

c. Chemical preservation

What are chemical food preservatives?

Chemical food preservatives are those substances that are added in very low quantities (up to 0.2%) and which do not alter the organoleptic and physic-chemical properties of the foods at or only very little. Many chemicals will kill micro-organisms or stop their growth but most of these are not permitted in foods; chemicals that are permitted as food preservatives are listed in Table 3.2.

Preservation of food products containing chemical food preservatives is usually based on the combined or synergistic activity of several additives, intrinsic product parameters (e.g. composition, acidity, water activity) and extrinsic factors (e.g. processing temperature, storage atmosphere and temperature).

Table 3.2: Chemical food preservatives

Agent	Acceptable Daily Intake (mg/Kg body weight)	Commonly used levels (%)
Lactic acid	No limit	No limit
Citric acid	No limit	No limit
Acetic acid	No limit	No limit
Sodium Diacetate	15	0.3-0.5
Sodium benzoate	5	0.03-0.2
Sodium propionate	10	0.1-0.3
Potassium sorbate	25	0.05-0.2
Methyl paraben	10	0.05-0.1
Sodium nitrite	0.2	0.01-0.02
Sulphur dioxide	0.7	0.005-0.2

Source: FDA, 1991

This approach minimizes undesirable changes in product properties and reduces the concentration of additives and the extent of processing treatments. The concept of combinations of preservatives and treatments to preserve foods is frequently called the hurdle or barrier concept. Combinations of additives and preservatives systems provide unlimited preservation alternatives for applications in food products to meet consumer demands for healthy and safe foods.

Chemical food preservatives are applied to foods as direct additives during processing or develop by themselves during processes such as fermentation. Certain preservatives have been used either accidentally or intentionally for centuries, and include sodium chloride (common salt), sugar, acids, alcohol and components of smoke. In addition to preservation, these compounds contribute to the quality and identity of the products and are applied through processing procedures such as salting, curing, fermentation and smoking.

Traditional chemical food preservatives used in fruit and vegetable processing technologies could be summarized as follows:

1. Common salt
2. Sugars (sucrose, glucose, fructose and syrups)
3. Foods preserved by high sugar concentrations: jellies, preserves, syrups, juice concentrates
4. Interaction of sugar with other ingredients or processes such as drying and heating
5. Indirect food preservation by sugar in products where fermentation is important (naturally acidified pickles and sauerkraut).
6. Acidulants and other preservatives formed in or added to fruit and vegetable products are as follows: Lactic acid, Acetic acid, Malic acid, tartaric (tartaric) acid, Citric acid, Ascorbic acid or vitamin C.
7. Lipophilic acid food preservatives: Commonly used are benzoic acid in the form of sodium salt and sorbic acid.
8. Gaseous chemical food preservatives: Sulphur dioxide and Sulphites, Carbon dioxide (CO_2), various forms of chlorine [such as sodium hypochlorite (NaOCl), calcium hypochlorite ($Ca(OCl)_2$) and chlorine dioxide gas (ClO_2].

General rules for chemical preservation

1. Chemical food preservatives have to be used only at a dosage level which is needed for normal preservation and not more.
2. "Reconditioning" of chemical preserved food, e.g. a new addition of preservative to stop a microbiological deterioration that already occurred is not recommended.

3. The use of chemical preservatives must be strictly limited to those substances which are recognized as being without harmful effects on human beings' health and are accepted by national and international standards and legislation.

Factors that determine/ influence the action of chemical food preservatives

General rules for chemical preservation

i. Factors related to the chemical preservatives:

a. Chemical composition

b. Concentration

ii. Factors related to micro-organisms:

a) Micro-organism species; as a general rule it is possible to take the following facts as a basis:

- Sulphur dioxide and its derivatives can be considered as a "universal" preservative; they have an antiseptic action on bacteria as well as on yeasts and moulds;
- benzoic acid and its derivatives have a preservative action that is stronger against bacteria than on yeasts and moulds;
- Sorbic acid acts on moulds and certain yeast species; in higher dosage levels it acts also on bacteria, except lactic and acetic ones;
- Formic acid is more active against yeasts and moulds and less on bacteria.

b) The initial number of micro-organisms in the treated product determines the efficiency of the chemical preservative.

iii. Specific factors related to the product to be preserved:

- Product chemical composition;
- Influence of the pH value of the product: the efficiency of the majority of chemical preservatives is higher at lower pH values, i.e. when the medium is more acidic.
- Physical presentation and size to which the product is sliced.
- : Temperature and Time

d. Preservation of vegetables by acidification

Food acidification is a means of preventing their deterioration in so far as a non-favourable medium for micro-organisms development is created. This acidification can be obtained in two ways: natural acidification and artificial acidification.

Natural acidification: This is achieved by a predominant lactic fermentation which assures the preservation-based on acidoceno-anabiosis principle; preservation by lactic fermentation is called also biochemical preservation. Throughout recorded history food has been preserved by fermentation. Despite the introduction of modern preservation methods, lactic acid fermented vegetables still enjoy great popularity, mainly because of their nutritional and gastronomic qualities. The various preservation methods discussed thus far, based on the application of heat, removal of water, cold and other principles, all have the common objective of decreasing the number of living organisms in foods or at least holding them in check against further multiplication.

Fermentation processes for preservation purposes, in contrast, encourage the multiplication of micro-organisms and their metabolic activities in foods. But the organisms that are encouraged are from a select group and their metabolic activities and end products are highly desirable. The extent of this desirability is emphasized by a partial list of fermented fruits and vegetable products from various parts of the world in Table 5.4.1. There are some characteristic features in the production of fermented vegetables which will be pointed out below using cucumbers as an example. In the production of lactic acid fermented cucumbers, the raw material is put into a brine without previous heating. Through the effect of salt and oxygen deficiency, the cucumber tissues gradually die. At the same time, the semi-permeability of the cell membranes is lost, whereby soluble cell components diffuse into the brine and serve as food substrates for the micro-organisms.

Under such specific conditions of the brine, the lactic acid bacteria succeed in overcoming the accompanying micro-organisms and lactic acid as the main metabolic products are formed. Under favourable conditions (for example moderate salt in the brine, use of starter cultures) it takes at least 3 days until the critical pH value of 4.1 or less - desired for microbiological reasons - is reached.

Besides the typical taste, for the consumer, a crisp texture is the most important quality criterion for fermented vegetables. Fig. 5.4.1 shows the factors which can influence the texture, where the enzymes are particularly important. Because there is no heating step before the fermentation, the indigenous plant enzymes in the fermenting materials are still present during the very first phase. After the destruction of the cell membranes, they easily get to their active sites and under favourable conditions, they can easily cause softening.

The environmental conditions act differently on single enzyme or enzymes systems: some enzymes are strongly inhibited by salt, others are activated, and in the acid pH region many enzymes are irreversibly inactivated. Besides indigenous enzymes also enzymes produced by micro-organisms can be responsible for the undesired soft products.
In technically advanced societies the major importance of fermented foods has come to be the variety they add to the diet. However, in many less developed areas of the world, fermentation and natural drying are

the major food preservation methods and as such is vital to the survival of a large proportion of the world's current population.

Artificial acidification: Artificial acidification is carried out by adding acetic acid which is the only organic acid harmless for human health and stable in specific working conditions; in this case, biological principles of the preservation are acidoanabiosys and, to a lesser extent, acidoabiosys.

Combined acidification

Combined acidification is a preservation technology that involves as a preliminary processing step a weak lactic fermentation followed by acidification (vinegar addition). The two main classes of vegetables preserved by acidification are sauerkraut and pickles. The definitions of these products are as follows:

Bulk sauerkraut: Bulk or barrelled sauerkraut is the product of characteristic acid flavour, obtained by the full fermentation, chiefly lactic, of properly prepared and shredded cabbage in the presence of 2-3% salt. On completion of fermentation, it contains not more than 1.5% of acid, expressed as lactic acid.

Canned sauerkraut: Canned (or packaged) sauerkraut, is prepared from clean, sound, well-matured heads of the cabbage plant (*Brassica oleracea* var. *capitata* L.) which have been properly trimmed and cut; to which salt is added and which is cured by natural fermentation.

The product may or may not be packed with pickled peppers, pimientos, or tomatoes or contain other flavouring ingredients to give the product specific flavour characteristics. The product

a) Maybe canned by processing sufficiently by heat to assure preservation in hermetically sealed containers; or
b) It May be packaged in sealed containers and preserved with or without the addition of benzoate of soda or any other ingredient permissible under the provisions of the Food and Drug Administration (FDA).

Pickles: "Pickles" means the product prepared entirely or predominantly from cucumbers (*Cucumis sativus* L.). Clean, sound ingredients are used which may or may not have been previously subjected to fermentation and curing in a salt brine (solution of sodium chloride, NaCl).

The prepared pickles are packed in a vinegar solution to which may be added salt and other vegetables, nutritive sweeteners, seasonings, flavourings, spices, and other ingredients permissible under FDA

regulations. The product is packed in suitable containers and heat-treated, or otherwise processed to assure preservation.
Sauerkraut and pickle products can be preserved under the effect of natural or added acidity, followed by pasteurization when this acidification is not sufficient.

Sauerkraut is a very good source of vitamin C; the importance of this product should be emphasised in developing countries as a simple technology that can be applied mainly for the consumption of the finished products in remote, isolated areas during the cold season.
Natural acidification preservation could be considered similar to sun/solar drying in terms of training and development.

e. Preservation with sugar

The principle of this technology is to add sugar in a quantity that is necessary to augment the osmotic pressure of the product's liquid phase at a level that will prevent microorganism development. From a practical point of view, however, it is usual to partially remove water (by boiling) from the product to be preserved, intending to obtain a higher sugar concentration. In concentrations of 60% in the finished products, the sugar generally assures food preservation. It is important to know the ratio between the total sugar quantity in the finished product and the total sugar concentration in the liquid phase because this determines, in practice, the sugar preserving action.

In the food preservation with sugar, the water activity cannot be reduced below 0.845; this value is sufficient for bacteria and entomophile yeast inhibition but does not prevent mould attack. For this reason, various means are used to avoid mould development, including (a) finished product pasteurization (jams, jellies, etc.) and (b) use of chemical preservatives to obtain the antiseptisation of the product surface.

It is very important from a practical point of view to avoid any product contamination after boiling and to assure a hygienic operation of the whole technological process (this will contribute to the prevention of product moulding or fermentation). Storage of the finished products in good conditions can only be achieved by ensuring the above level of water activity.

f. Heat preservation/heat processing

Various degrees of preservation

There are various degrees of preservation by heating; a few terms have to be identified and understood.

a. Sterilization: By sterilization, we mean destruction of micro-organisms. Because of the resistance of certain bacterial spores to heat, this frequently means treatment of at least 121° C (250° F) of wet heat for 15 minutes or its equivalent. It also means that every particle of the food must receive this heat treatment. If a can of food is to be sterilized, then immersing it into a 121° C pressure cooker or retort for 15 minutes will not be sufficient because of a relatively slow rate of heat transfer through the food in the can to the most distant point.

b. "Commercially sterile": This term describes the condition that exists in most the canned or bottled products manufactured under Good Manufacturing Practices procedures and methods; these products generally have a shelf-life of two years or more.

c. Pasteurization - a comparatively low order of heat treatment, generally at a temperature below the boiling point of water. The more general objective of pasteurization is to extend product shelf-life from a microbial and enzymatic point of view; this is the objective when fruit or vegetable juices and certain other foods are pasteurized. Pasteurization is frequently combined with other means of preservation - concentration, chemical, acidification, etc.

d. Blanching is a type of pasteurization usually applied to vegetables mainly to inactivate natural food enzymes. Depending on its severity, blanching will also destroy some microorganisms.

Determining heat treatment/thermal processing steps

Since heat sufficient to destroy micro-organisms and food enzymes also usually have adverse effects on other properties of foods, in practice the minimum possible heat treatment should be used which can guarantee freedom from pathogens and toxins and give the desired storage life; these aims will determine the choice of heat treatment.

To safely preserve foods using heat treatment, the following must be known:

a) What time-temperature combination is required to inactivate the most heat resistant pathogens and spoilage organisms in one particular food?

b) What are the heat penetration characteristics in one particular food, including the can or container of choice if it is packaged?

Preservation processes must provide the heat treatment which will ensure that the remotest particle of food in a batch or within a container will reach a sufficient temperature, for a sufficient time, to inactivate both the most resistant pathogen and the most resistant spoilage organisms if it is to achieve sterility or "commercial sterility", and to inactivate the most heat resistant pathogen if pasteurization for public health purposes is the goal.

Different foods will support the growth of different pathogens and different spoilage organisms so the target will vary depending upon the food to be heated. Food acidity/pH value has a tremendous impact on the target in heat preservation/ processing.

The sequence of operations employed in heat preservation of foods (fruit and vegetables, etc.)

In a simplified manner, the main operations employed in heat preservation can be described as seen in Table 3.3.

Table 3.3: Main operations employed in heat preservation

Food 00preparation	Preparation procedures will vary with the type of food. For fruit, washing, sorting, grading, peeling, cutting to size, pre-cooking and pulping operations may be employed.
Can/receptacle	This may be carried out manually or by using sophisticated filling machinery. The ratio of liquid to solid in the can must be carefully controlled and the can must not be overfilled. A headspace of 6-9 mm depth (6-8% of the container volume) above the level of food in the can as usual.
Vacuum production	This can be achieved by filling the heated product into the can, heating the can and contents after filling, evacuating the headspace gas in a vacuum chamber, or by injecting superheated steam into the headspace. In each case the can end is seamed on immediately afterwards.
Thermal processing	The filled sealed can be heated to a high temperature for a sufficient length of time to ensure the destruction of spoilage micro-organisms. This is usually carried out in an autoclave or retort, in an environment of steam under pressure.
Cooling	The processed cans must be cooled in chlorinated water to a temperature of 37°C. At this temperature, the heat remaining is sufficient to allow the water droplets on the can to evaporate before labelling and packing.
Labelling and packing	Labels are applied to the can body, and the cans are then packed into cases.

In principle, all these operations can also be carried out at the farm/community level using the appropriate small scale equipment, preferably only glass jars (e.g. no metal cans).

Technological principles of pasteurization

Physical and chemical factors which influence the pasteurization process are as follows:

a. temperature and time
b. the acidity of the products
c. air remaining in containers

Pasteurisation processes: In pasteurizing certain acid juices, for example, there are two categories of processes:

(a) Low pasteurization where pasteurization time is in the order of minutes and related to the temperature used; two typical temperature/time combinations are as follows: 63° C to 65° Cover 30 minutes or 75°C over 8 to 10 minutes.

Pasteurization temperature and time will vary according to nature of the product, initial degree of contamination, pasteurized product storage conditions and shelf life required. In this first category of pasteurization processes it is possible to define three phases:

- Heating to a fixed temperature
- Maintaining this temperature over the established period (= pasteurization time)
- Cooling the pasteurized products: natural (slow) or forced cooling.

b) Rapid, high or flash pasteurization is characterized by a pasteurization time in the order of seconds and temperatures of about 85° to 90° C or more, depending on holding time. Typical temperature/time combinations are as follows:
88° C (190° F) for 1 minute
100° C for 12 seconds
121°C for 2 seconds

While bacterial destruction is very nearly equivalent in low and high pasteurization processes, the 121° C/2 seconds treatment gives the best quality products in respect of flavour and vitamin retention. Such short holding times, however, require special equipment which is more difficult to design and generally is more expensive than the 63-65 ° C/30 minutes type of processing equipment.

In flash pasteurization, the product is heated up rapidly to pasteurization temperature, maintained at this temperature for the required time, then rapidly cooled down to the temperature for filling, which will be performed in aseptic conditions in sterile receptacles. Taking into account the short time and rapid performance of this operation, flash pasteurization can only be achieved in a continuous process, using heat exchangers. Industrial applications of the pasteurization process are mainly used as a means of preservation for fruits and vegetable juices and especially for tomato juice.

g. Food irradiation

Food irradiation is one of the food processing technologies available to the food industry to control organisms that cause food-borne diseases and to reduce food losses due to spoilage and deterioration. Food irradiation technology offers some advantages over conventional processes. Each application should be evaluated on its merit as to whether irradiation provides a technical and economical solution that is better than traditional processing methods.

Applications

For products where irradiation is permitted, commercial applications depend on several factors including the demand for the benefits provided, competitiveness with alternative processes and the willingness of consumers to buy irradiated food products. There are several applications of food irradiation. For each application, it is important to determine the optimum dosage range required to achieve the desired effect. Too high a dosage can produce undesirable changes in texture, colour and taste of foods.

Shelf-life extension

Irradiation can extend the shelf-life of foods in several ways. By reducing the number of spoilage organisms (bacteria, mould, fungi), irradiation can lengthen the shelf life of fruits and vegetables. Since ionizing radiation interferes with cell division, it can be used as an alternative to chemicals to inhibit sprouting and thereby extend the shelf life of potatoes, onions and garlic. Exposure of fruits and vegetables to ionizing radiation slows their rate of ripening. Strawberries, for example, are suitable for irradiation. Their shelf-life can be extended three-fold, from 5 to 15 days.

Disinfestation

Ionizing radiation can also be used as an alternative to chemical fumigants for the disinfestation of grains, spices, fruits and vegetables. Many countries prohibit the importation of products suspected of being contaminated with live insects to protect the importing country's agricultural base. With the banning of certain chemical fumigants, irradiation has the potential to facilitate the international shipment of food products.

Challenges in the storage of vegetables and fruits

Like the root crops, fruits and vegetables consist to a large extent of water. And just like for root crops, one challenge is to retain that water

during storage. The shelf life of fruits and vegetables can be a couple of months for some products, but this is an exception rather than the rule. For most fruits and vegetables it varies from only a few days to several weeks.
A farmer needs to know which fruits and vegetables ripen in which season to have different fruits and vegetables available for consumption in every season. For some annual fruits and vegetables, it may be possible to plant them at several dates so that the harvest period for that fruit or vegetable is prolonged. The conditions in the field at the time of harvest differ considerably from the optimum conditions for storage. In the field, it is often hot and dry. Under these conditions, the products start to deteriorate and lose water as soon as they are detached from the plant. Therefore, short-lived products should either be consumed directly or put in store shortly after harvest. They should not be handled for several days before they are brought under optimum storage conditions.

All fruits and vegetables are easily bruised by carelessness during harvest, transport and other activities. Bruises may not be visible, but decay will begin under the skin. As a consequence of bruising, the already short shelf life becomes even shorter. Handling the products carefully to prevent bruises is thus very important. Fruits and vegetables are not only an important food source for the family, but they can also bring a good price if sold on the market. The costs for storage, transport and handling will pay off for products that are of the uppermost quality. Farmers should keep in mind, however, that traders tend to pay a too-low price for products with a short shelf-life; selling directly to consumers will always bring a better price. It is important to remember that consumers like products that look fresh and are of uniform size and good quality.

If farmers cannot afford to pay for storage and other facilities, it may be possible to share these costs by starting a cooperative of several farmers.

SELF-ASSESSMENT EXERCISE

i. What are the challenges in the storage of vegetables and fruits.
ii. List the main operations employed in heat preservation.
iii. What are chemical food preservatives.

4.0 CONCLUSION

Durable crop products have favourable natural properties that make them suitable for storage over an extended period, but the fresh, non-processed forms of perishable crops are less conducive to storage and, without specialist storage environments, their conservation is limited to days or possibly weeks.

5.0 SUMMARY

There are various methods by which fruits and vegetables can be preserved, including **p**reservation by drying/dehydration, Preservation by concentration, Chemical preservation, preservation by acidification, preservation with sugar and heat preservation.

In practice, preservation procedures aim at avoiding microbiological and biochemical deterioration which are the principal forms of deterioration. Even with all recent progress achieved in this field, no single one of these technological procedures applied alone can be considered wholly satisfactory from a microbiological, physicochemical and organoleptic point of view, even if to a great extent the food value is assured.

It should be noted that (i) Some of these preservation procedures are applied only to one or some categories of foods while others can be used across the board and thus have a wider application (cold storage, freezing, drying/dehydration, sterilization, etc.), and (ii) Some guarantee food preservation on their own while others require combination with other procedures, either as principal or as auxiliary processes to assure preservation (for example smoking has to be preceded by salting).

6.0 TUTOR MARKED ASSIGNMENT (TMA)

1. List the main operations employed in heat preservation.
2. List the factors that influence the action of chemical food preservatives.
3. General rules for chemical preservation.
4. Define blanching.
5. State three (3) advantages of blanching.

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UNIT 5 STORAGE AND SHELF-LIFE PROBLEMS IN CROP PRODUCTS

CONTENTS

1.0 INTRODUCTION

In the field and during storage crop products are threatened by insects, rodents, birds and other pests. Moreover, the product may be spoiled by infection from fungi, yeasts or bacteria Losses in quantity and quality affect crops between harvest and consumption. The magnitude of postharvest losses in fresh fruits and vegetables is an estimated 5 to 25 per cent in developed countries and 20 to 50 per cent in developing countries, depending upon the commodity, cultivar and handling conditions. To reduce these losses, producers and handlers must understand the biology and environmental factors involved in deterioration.

Fresh fruits, vegetables and ornamentals are living tissues that are subjected to continuous change after harvest. While some changes are desirable, most from a consumer standpoint are not. Post-harvest changes in fresh produce cannot be stopped, but they can be slowed within certain limits.

2.0 OBJECTIVES

By the end of this unit you should be able to:

- describe problems of crop storage
- describe methods of shelf-life extension of crop produce
- know the agents that cause in stored grain
- know the biological factors that cause deterioration in horticultural crops
- know the technical methods of reducing crop deterioration

3.5.3 Storage and Shelf-Life Problems in Crop Products

3.5.3.1 Agents Causing Deterioration of Stored Grains

The principal enemies of stored grain are (i) Micro-organisms, (ii) Insects and (iii) Rodents.

i. **Micro-organisms:** Micro-organisms (moulds, yeasts, bacteria) are biological agents present in the soil which, when transported by air or water, can contaminate products before, during and after the harvest. Their presence and growth cause severe changes in the nutritive value and the organoleptic features of grain (taste, smell, aspect). Furthermore, they are responsible for the alteration of important germinative properties of seeds (vigour and capacity to germinate) and, in the case of moulds, for the potential formation of dangerous poisons (mycotoxins).

   Impurities, and cracked or broken grains, foster the development of micro-organisms. Furthermore, temperature and humidity have a determining influence on the growth rate of these degradation agents. It has been observed that micro-organisms develop at temperatures between -8°C and +80°C when the relative humidity of the air is over 65 per cent. On the contrary, atmospheres that are low in oxygen help check the development of these degradation agents.

ii. **Insects:** Insect infestations can occur either in the field, before the harvest, or in the places where products are stored. In some cases, these infestations are difficult to discern with the naked eye, since the damage is provoked by the larvae developing inside the grain.

The insects most likely to infest stored products belong to the following families:

- Coleoptera (damage by larvae and adult)
- Lepidoptera (damage only by larvae)

Insects can be responsible for significant losses of product. Furthermore, their biological activity (waste production, respiration, etc.) compromises the quality and commercial value of the stored grain and fosters the development of micro-organisms. Insects can live and reproduce at temperatures between +15°C and +35ºC. On the contrary, low humidity slows or even stops their development, and a low supply of oxygen rapidly kills them.

iii. **Rodents:** Rodents invade and multiply in or near storage places, where they can find an abundance of food. They cause serious damage not only to stored products but also to packaging and even to storage buildings. The principal rodents, those most common and likely to attack stored products, belong to the following species:

- The black rat also called roof rat (*Rattus rattus*)
- Brown or Norway rat, also called sewer rat (*Rattus norvegicus*)
- Mouse (*Mus musculus*)

Prolonged attacks by these pests inevitably result in serious quantitative losses of stored products. To these losses must be added those arising from the decrease in quality of the foodstuffs, caused by the filth (excrement, secretions) rodents leave behind in the stored products. This contamination is as important from the marketing standpoint as it is for hygiene and health. Indeed, rodents are often the vectors of serious diseases (rabies, leptospirosis).

3.5.3.2 Biological Factors Involved in Deterioration of Horticultural Crops

a. Respiration

The rate of deterioration (perishability) of harvested commodities is generally proportional to the respiration rate.

Based on their respiration and ethylene production patterns during maturation and ripening, fruits are either climacteric or non-climacteric. Climacteric fruits show a large increase in CO_2 and C_2H_4 production rates coincident with ripening, while non-climacteric fruits show no change in their generally low CO_2 and C_2H_4 production rates during ripening.

Table 3.4: Horticultural commodities classified according to their respiration rates

Class	**Range at 5°C (mg CO_2/kg-hr)**	**Commodities**
Very low	<5	Dates, dried fruits and vegetables, nuts
Low	5-10	Apple, beet, celery, citrus fruits, cranberry, garlic, grape, honeydew melon, kiwifruit, onion, papaya, persimmon, pineapple, potato (mature), sweet potato, watermelon

Moderate	10-20	Apricot, banana, blueberry, cabbage, cantaloupe, carrot (topped), celeriac, cherry, cucumber, fig, gooseberry, lettuce (head), mango, nectarine, olive, peach, pear, plum, potato (immature), radish (topped), summer squash, tomato
High	20-40	Avocado, blackberry, carrot (with tops), cauliflower, leeks, lettuce (leaf), lima bean, radish (with tops), raspberry
Very high	40-60	Artichoke, bean sprouts, broccoli, Brussels sprouts, cut flowers, endive, green onions, kale, okra, snap bean, watercress
Extremely high	>60	Asparagus, mushroom, parsley, peas, spinach, sweet corn

Table 3.5: Fruits classified according to respiratory behaviour during ripening

Climacteric fruits		**Non-climacteric fruits**	
Apple	Muskmelon	Blackberry	Lychee
Apricot	Nectarine	Cacao	Okra
Avocado	Papaya	Carambola	Olive
Banana	Passion fruit	Cashew	Orange
Biriba	Peach	Cherry	Peas
Blueberry	Pear	Cucumber	Pepper
Breadfruit	Persimmon	Date	Pineapple
Cherimoya	Plantain	Eggplant	Pomegranate
Durian	Plum	Grape	Prickly pear

Feijoa	Quince	Grapefruit	Raspberry
Fig	Rambutan	Jujube	Strawberry
Guava	Sapodilla	Lemon	Summer squash
Jackfruit	Sapote	Lime	Tamarillo
Kiwifruit	Soursop	Longan	Tangerine/Mandarin
Mango		Loquat	Watermelon
Tomato		Apple	

b. Ethylene production

Ethylene the simplest of the organic compounds affecting the physiological processes of plants is a natural product of plant metabolism and is produced by all tissue of higher plants and by some microorganisms. As a plant hormone, ethylene regulates many aspects of growth, development and senescence and is physiologically active in trace amounts (less than 0.1 ppm). It also plays a major role in the abscission of plant organs.

Generally, ethylene production rates increase with:

i. Maturity at harvest
ii. Physical injuries
iii. Disease
iv. High or low temperature
v. Water stress

Ethylene production can be reduced by the following:

i. Reducing the storage temperature
ii. Reducing O_2 levels to less than 8%
iii. Treating with the inhibitors AVG, AOA or cobalt chloride
iv. Genetic engineering

Ethylene action can be blocked by the following:

i. Treating with silver thiosulphate (commonly used in flowers)
ii. Hypobaric storage - keeping the commodity under vacuum
iii. Elevating CO_2 to more than 2%
iv. Genetic engineering

c. Compositional changes

1. Pigments

Many changes in pigments take place during the development and maturation of a given commodity, some of which may continue the following harvest. These changes may either be good or bad. Some pigments that change include the following

i. Chlorophyll (Green colour) - a loss of chlorophyll in tomatoes is good but a loss in chlorophyll in broccoli is bad;
ii. Carotenoids (Yellow, Orange and Red colours) - Carotenoids are desirable in fruits such as apricots, peaches and citrus giving them their yellow and orange colour. In tomatoes and pink grapefruit, a specific carotenoid called lycopene gives them their red colour.
iii. Anthocyanins (Red and Blue colours) - Anthocyanins give red and blue colour to apples, berries, cherries etc.; and
iv. Phenolic compounds - Are responsible for tissue browning.

Table 3.6: Horticultural commodities classified according to their ethylene production rates

Class	**Range at 20°C (µl C_2H_4/kg-hr)**	**Commodities**
Very low	<0.1	Artichoke, asparagus, cauliflower, cherry, citrus fruits, grape, jujube, strawberry, pomegranate, leafy vegetables, root vegetables, potato, most cut flowers
Low	0.1 - 1.0	Blackberry, blueberry, casaba melon, cranberry, cucumber, eggplant, okra, olive, pepper (sweet and chilli), persimmon, pineapple, pumpkin, raspberry, watermelon
Moderate	1.0 – 10	Banana, fig, guava, honeydew melon, lychee, mango, plantain, tomato
High	10-100	Apple, apricot, avocado, cantaloupe, kiwifruit (ripe), nectarine, papaya, peach, pear, plum
Very high	>100	Cherimoya, passion fruit, sapota

2. Carbohydrates

i. Conversion of starch to sugar - Not desirable in potato but very desirable in apples, bananas.
ii. Conversion of sugar to starch - Not desirable in sweet corn but very desirable in potatoes.
iii. Conversion of starch and sugars to CO_2 and water during respiration - Not desirable because it leads to a reduction in quality.

3. Others

Changes in organic acids, proteins, amino acids and lipids can also influence quality.

d. Growth and development

Sprouting of potatoes, onions, garlic and root crops greatly reduces their food value and accelerates deterioration. Rooting of Onions and root crops is also undesirable. Asparagus spears continue to grow after harvest; elongation and Curvature (if the spears are held horizontally) are accompanied by increased toughness and decreased palatability. Seed germination inside fruits such as tomatoes, peppers and lemons is an undesirable change.

e. Transpiration

Water loss is the main cause of deterioration because it results not only in direct quantitative losses (loss of salable weight) but also in losses in appearance (wilting and shrivelling), textural quality (softening, loss of crispness and juiciness) and nutritional quality.

The commodity's dermal system (outer protective coverings) governs the regulation of water loss. It includes the cuticle, epidermal cells, stomata, lenticels, and trichomes (hairs). The cuticle is composed of surface waxes, cutin embedded in wax, and a layer of mixtures of cutin, wax, and carbohydrate polymers. The thickness, structure, and chemical composition of the cuticle vary greatly among commodities and developmental stages of a given commodity.

The transpiration rate (evaporation of water from the plant tissues) is influenced by internal, or commodity, factors (morphological and anatomical characteristics, surface-to-volume ratio, surface injuries, and maturity stage) and by external, or environmental, factors (temperature, relative humidity [RH], air movement, and atmospheric pressure). Transpiration is a physical process that can be controlled by applying treatments to the commodity (e.g., waxes and other surface coatings or wrapping with plastic films) or by manipulating the environment (e.g., maintaining high RH and controlling air circulation).

f. Physiological breakdown

Exposure of commodities to undesirable temperatures can result in physiological disorders.

Freezing injury results when commodities are held below their freezing temperatures. The disruption caused by freezing usually results in the immediate collapse of the tissues and total loss of the commodity.

Chilling injury occurs in some of the commodities (mainly those of tropical and subtropical origin) held at temperatures above their freezing point and below 5 to 15°C depending upon the commodity. Chilling injury symptoms become more noticeable upon transfer to higher (non-chilling) temperatures. The most common symptoms are surface and internal discolouration (browning), pitting, water-soaked areas, uneven ripening, off-flavours development and accelerated incidence of surface moulds and decay.

Heat injury is induced by exposure to direct sunlight or excessively high temperatures. Its symptoms include bleaching, surface burning, uneven ripening and excessive softening.

g. Physical and pathological damage

Mechanical injuries causing bruising lead to water loss, fungal infection and stimulate respiration and ethylene production leading to a loss in quality.

3.5.3.3 Technical Methods of reducing Food Deterioration

The technical means for reducing food deterioration can be summarized as follows as presented in Table **3.7**.

Table 3.7: Technical means for reducing food deterioration

Physical	Heating
	Cooling
	Lowering of water content Drying/dehydration. Concentration
	Sterilizing filtration
	Irradiation
	Other physical means (high pressure, vacuum, inert gases)
Chemical	Salting
	Smoking
	Sugar addiction
	Artificial acidification
	Ethyl alcohol addition
	Antiseptic substance action
Biochemical	Lactic fermentation (natural acidification)
	Alcoholic fermentation

3.5.3.4 Methods of Shelf life extension

1. **Canning:** Canning is a method of preserving food in which the food is processed and sealed in an airtight container. The process was first developed as a French military discovery by Nicolas Appert. The packaging prevents microorganisms from entering and proliferating inside. To prevent the food from being spoiled before and during containment, quite a several methods are used: pasteurization, boiling (and other applications of high temperature over some time), refrigeration, freezing, drying, vacuum treatment, antimicrobial agents that are natural to the recipe of the foodstuff being preserved, a sufficient dose of ionizing radiation, submersion in a strongly saline, acid, base, osmotically extreme (for example very sugary) or other microbe-challenging environments. No such method is perfectly dependable as a preservative. For example, spore-forming thermal resistant microorganisms, such as Clostridium botulinum (which causes botulism) can still survive.

   From a public safety point of view, foods with low acidity (a pH of more than 4.6) need sterilization under high temperatures (116-130°C). To achieve temperatures above the boiling point requires the use of a pressure canner. Foods that must be pressure could include most vegetables, meats, seafood, poultry, and dairy products. The only foods that may be safely canned in an ordinary boiling water bath are highly acidic ones with a pH below 4.6 such as fruits, pickled vegetables, or other foods to which acidic additives have been added.

2. **Drying:** One of the oldest methods of Shelf life extension is drying, which reduces water activity sufficiently to prevent or delay bacterial growth. Drying also reduces weight, making food more portable. Most types of meat can be dried; a good example is beef biltong. Many fruits can also be dried; for example, the process is often applied to apples, pears, bananas, mangoes, papaya, apricot, and coconut. Zante currants, sultanas and raisins are all forms of dried grapes. Drying is also the normal means of preservation for cereal grains such as wheat, maize, oats, barley, rice, millet and rye.

3. **Freezing:** Freezing is also one of the most commonly used processes commercially and domestically for preserving a very wide range of food including prepared foodstuffs which would

not have required freezing in their unprepared state. For example, potato waffles are stored in the freezer, but potatoes themselves require only a cool dark place to ensure many months' storage. Cold stores provide large-volume, long-term storage for strategic food stocks held in case of national emergency in many countries.

4 **Vacuum packing:** Vacuum-packing stores food in a vacuum environment, usually in an air-tight bag or bottle. The vacuum environment strips bacteria of oxygen needed for survival, slowing spoiling. Vacuum-packing is commonly used for storing nuts to reduce the loss of flavour from oxidation.

4 **Use of Sugar:** Sugar is used to preserve fruits, either in syrup with fruit such as apples, pears, peaches, apricots, plums or in a crystallized form where the preserved material is cooked in sugar to the point of crystallization and the resultant product is then stored dry. This method is used for the skins of citrus fruit (candied peel), angelica and ginger. A modification of this process produces glace fruit such as glace cherries where the fruit is preserved in sugar but is then extracted from the syrup and sold, the preservation being maintained by the sugar content of the fruit and the superficial coating of syrup. The use of sugar is often combined with alcohol for the preservation of luxury products such as fruit in brandy or other spirits. These should not be confused with fruit-flavoured spirits such as cherry brandy or Sloe gin.

6 **Canning and bottling:** Canning involves cooking food, sealing it in sterile cans or jars, and boiling the containers to kill or weaken any remaining bacteria as a form of sterilization, inventor Nicolas Appert. Various foods have varying degrees of natural protection against spoilage and may require that the final step occurs in a pressure cooker. High-acid fruits like strawberries require no preservatives to can and only a short boiling cycle, whereas marginal fruits such as tomatoes require longer boiling and the addition of other acidic elements. Low acid foods, such as vegetables and meats require pressure canning. Food preserved by canning or bottling is at immediate risk of spoilage once the can or bottle has been opened.

Lack of quality control in the canning process may allow ingress of water or microorganisms. Most such failures are rapidly detected as decomposition within the can cause gas production and the can will swell or burst. However, there have been examples of poor manufacture (under processing) and poor hygiene allowing contamination of canned food by the obligate anaerobe Clostridium botulinum, which produces an acute toxin within the food, leading to severe illness or death. This organism produces no gas or obvious taste and remains undetected by taste or smell. Its toxin is denatured by cooking, though. Cooked mushrooms, handled poorly and then canned, can support the growth of *Staphylococcus aureus*, which produces a toxin that is not destroyed by canning or subsequent reheating.

7 **Pulsed Electric Field Processing:** Pulsed electric field (PEF) processing is a method for processing cells through brief pulses of a strong electric field. PEF holds potential as a type of low-temperature alternative pasteurization process for sterilizing food products. In PEF processing, a substance is placed between two electrodes, then the pulsed electric field is applied. The electric field enlarges the pores of the cell membranes which kills the cells and releases their contents. PEF for food processing is a developing technology still being researched. There have been limited industrial applications of PEF processing for the pasteurization of fruit juices.

8 **High pressure:** High-pressure Shelf life extension refers to high pressure used for Shelf life extension. Pressed inside a vessel exerting 70,000 pounds per square inch or more, food can be processed so that it retains its fresh appearance, flavour, texture and nutrients while disabling harmful microorganisms and slowing spoilage. By 2001, adequate commercial equipment was developed so that by 2005 the process was being used for products ranging from orange juice to guacamole to deli meats and widely sold.

SELF-ASSESSMENT EXERCISE

In a tabular form, present the technical means for reducing food deterioration

4.0 CONCLUSION

The magnitude of postharvest losses in agricultural products can be reduced if producers and handlers understand the biology and environmental factors involved in deterioration.

5.0 SUMMARY

The principal enemies of stored grain are (i) Micro-organisms, (ii) Insects and (iii) Rodents. Atmospheres that are low in oxygen help check the development of microorganisms; low humidity slows or even stops the development of insects, and a low supply of oxygen rapidly

kills them. Biological factors such as respiration, ethylene production, transpiration and physiological breakdown all contribute to the deterioration of fruits and vegetables.
The shelf-life of crops can be extended through canning, drying, freezing, vacuum packing, use of sugar, bottling, pulsed electric field processing and the use of high pressure.

6.0 TUTOR MARKED ASSIGNMENT (TMA)

1. List five (5) methods of extending the shelf-life of horticultural crops and discuss any two (2).
2. What are the chemical means by which food deterioration can be reduced?
3. How can ethylene production be reduced?

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MODULE 4 IDEAL ENVIRONMENT FOR STORAGE

UNIT 1 ENVIRONMENTAL FACTORS AFFECTING POST-HARVEST LIFE OF CROP PRODUCE

CONTENTS

1.0 INTRODUCTION

Stored food, both perishable and durable, may be considered to be an ecosystem, i.e. a system that includes a group of organisms and their environment. The interactions between the physical, chemical and biological factors within the ecosystem lead to changes in the quality and nutritive value of the stored product. Knowledge of these factors is therefore essential if the quality and quantity of stored products are to be maintained. In this unit we will look at the environmental factors that influence both the quantity and quality of a harvest. They include temperature, relative humidity, moisture, atmospheric composition and light

2.0 OBJECTIVES

By the end of studying this unit you should be able to:

- discuss the environmental factors that affect post-harvest life of crop produce
- convert between wet basis and dry basis moisture contents of crops using the appropriate formula.
- know the recommended moisture content for long-term storage of grains in hot regions

3.0 MAIN CONTENT

3.1 Environmental Factors affecting Post-harvest Life of Crop Produce

1. Temperature

Temperature is the most important environmental factor which influences the postharvest life of a produce. Temperature and moisture are determining factors in accelerating or delaying the complex phenomena of the biochemical transformation (especially the "breathing" of the grain) that are at the origin of grain degradation. Furthermore, they have a direct influence on the speed of development of insects and microorganisms (moulds, yeasts and bacteria), and on the premature and unseasonal germination of grain.

In Table 4.1 below, the relationship between temperature and moisture content is established in order to determine the area of influence of certain important degradation phenomena, such as: the development of insects and moulds, and the germination of grain. It is easy to observe that the higher the temperature, the lower must be the moisture of the grain in order to ensure good conservation of the products.

In view of their influence on the speed of development of these degradation phenomena, the temperature and moisture content of the grain condition the maximal duration of storage. As an example, Table 1 shows the recommended durations of warehousing, according to the temperature and moisture content of the grain. The temperature depends not only on climatic conditions but also on the biochemical changes that are produced inside a grain mass, provoking undesirable natural heating of the stored products.

Temperature affects the rate of all biochemical processes and is therefore of fundamental importance in any storage system. Together with moisture content, it largely determines the storage life of grain. The temperature of the stored product and that of the air around and within it are both important. Insect, mite, fungal and mycotoxin development, germination loss and baking qualities are affected by temperature. At temperatures found in grain stores, biological activity of insects, mites, fungi and the grain itself doubles for every 10°C rise in temperature... At low temperatures insect breeding stops and less moisture is available for potential pests in cold grain. Grain should therefore be cooled immediately after drying and before it comes into store. Cooling during storage will also equalize temperature gradients and so prevent moisture translocation.

Biochemical activity due to moulds, insects, etc. can also be a source of heating during storage, as can transfer of heat energy to or from the fabric of the store by radiation. Ventilation of the store and, in particular, movement of air directly through the stored product, is one of the main ways of modifying storage temperatures.

Temperature greatly affects water loss. Lowering the temperature also slows the pathogen development. Temperatures outside the optimal range can cause chilling injury, freezing or heat injuries. The severity of chilling, freezing and heat injuries depend on the storage duration and temperature. Among these three injuries, chilling injury is the most known and threat for storage. The critical temperature for chilling injury is mainly below 5–13°C depending on produce and maturity stage. Chilling injury symptoms differ among commodities but generally include brown discoloration of the skin, necrotic pitting, and increased susceptibility to decay. Intermitted warming, application of some essential oils, salicylic acid, jasmonic acid, calcium chloride, etc. are reported to be helpful in delaying or preventing chilling injury.

Table 4.1: Relationship between temperature and moisture content

	Temperature/Duration of warehousing (in days)					
Moisture	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**
13%				180	115	90
14%			160	100	50	30
15%			100	50	30	15
16%		130	50	30	20	8
17%		65	35	22	12	5
18%	130	40	25	17	8	2
19%	70	30	17	12	5	0
20%	45	22	15	8		
21%	30	17	11	7		
22%	23	3	8	6		
23%	17	10	7	5		
24%	13	8	4	4		
25%	10	8	6	3		

2. Moisture

The moisture content of the stored grain depends on the relative humidity of the air. With a relative air humidity below 65-70 percent, many grain-degradation phenomena are slowed down, if not completely blocked. In this sense, the "safeguard" moisture content is defined as that corresponding to an equilibrium with the air at 65-70 percent relative humidity.

Table 4.2 shows the moisture content recommended for long-term storage of various sorts of grains in hot regions. Many stored products are hygroscopic materials, which means that they can absorb and release water, rather like a sponge. They thus consist of an amount of dry matter and an amount of water. The moisture content (m.c.) expresses the weight of water in a product as a proportion of its weight. The most common method of expression is known as the wet basis, in which the weight of the product is taken as the weight of the dry matter plus water.

Table 4.2: Recommended moisture content for long-term storage of grains in hot regions

S/No.	**Grain**	**Moisture**	**S/No**	**Grain**	**Moisture**
1	Paddy	14.0%	7	Sunflower	9.0%
2	Rice	13.0%	8	Wheat	13.0%
3	Maize	13.0%	9	Millet	16.0%
4	Sorghum	12.5 %	10	Coffee	13.0%
5	Beans	15.0%	11	Cocoa	7.0%
6	Groundnut	7.0 %	12	Copra	7.0 %

In scientific work the dry basis may be preferred, in which the weight of the product is taken as that of the dry matter only.

$$\text{m.c. (wet basis)} = \frac{\text{weight of water in sample}}{\text{wet sample weight (i.e. weight of water + dry matter)}} \times 100\%$$

$$\text{m.c. (dry basis)} = \frac{\text{weight of water in sample}}{\text{dry sample weight (i.e. weight of dry matter)}} \times 100\%$$

The two equations can be used to convert between wet basis and dry basis moisture contents.

3. Relative humidity

Relative humidity is more useful than absolute measures of humidity for determining the response of living things or biological materials to the air around them. For example, the ability of the air to dry water from crops or sweat from our skin depends on the degree to which it is saturated, i.e. on its relative humidity. Most importantly, in food storage the relative humidity of air around the product is one of the most important factors controlling spoilage by micro-organisms. Water vapour in the air around a stored product interacts with the water held in the product, so when stored products are present the relative humidity depends not only on the partial pressure of the water and temperature but also on the moisture content of the stored product. Hazards occur when the temperature falls at night and the relative humidity of the air rises. If the temperature falls by a large enough amount the relative humidity of the air can rise to 100% and liquid water will begin to condense out. It is clearly undesirable to bring air in this condition into contact with a stored commodity.

Problems can also occur within storage buildings or structures. The roof of a warehouse can get very cold at night while air rising from stored produce, for example, a bag stack of grain, may be relatively warm and moist. The air will cool and can reach saturation in contact with the cold roof. Condensation will then occur on the underside of the roof, causing water to drip on to the bag stack below and form a wet layer which will spoil due to mould growth. Another example occurs when commodities are transported within steel shipping containers from tropical to temperate climates (Gough 1996). The containers remain warm when packed together in the hold of the ship, but their surfaces cool rapidly if they are unloaded in cold weather on arrival. Warm moist air from the commodity can reach saturation in contact with the sides and roof of the container, giving rise to the phenomenon of internal raining in which condensation rains down onto the commodity and leads to spoilage.

While fruits and vegetables contain between 80 and 95% water by weight, it is important to provide favorable environmental conditions to reduce transpiration of the produce. Higher relative humidity (85–95%) slows water loss from the commodity. However, at the same time, high relative humidity might stimulate pathogen development and might weaken the packaging materials (e.g. cartoon boxes).

4. Atmospheric composition

Like grain, micro-organisms and insects are living organisms that need oxygen. Storage of grain in places that are low in oxygen causes the death of insects, cessation of development of micro-organisms, and blockage, or slowing down, of the biochemical phenomena of grain degradation. This favours the conservation of grain, but may affect its germinating power.

Regulating the gas concentrations in the surrounding atmosphere of the produce is important for reducing respiration and increasing preservation time. Reduction of O_2 and elevation of CO_2 can delay deterioration of fresh horticultural crops. However, it is highly depended on the type of commodity, cultivar, maturity, and temperature. Modified atmosphere packaging (MAP) is a useful system which makes it possible to regulate the composition of the atmosphere in the packaging headspace. During respiration, O_2 is consumed, and CO_2, ethylene, and water vapor are generated, thus the packaging material allows the transfer of all of these gasses through the packaging material by regulating the inner composition at favorable levels to preserve the produce. MAP slows down respiration and other metabolic processes, reduces sensitivity to ethylene, reduces the development of some physiological disorders (e.g. chilling injury) and may inhibit pathogen development.

5. Light

Light is also a cause of some abnormal changes in product quality. It might affect some biological process. For example, exposure of potatoes to light would results in formation of chlorophyll, which appears as greening and formation of solanine which is known to be toxic to humans.

SELF-ASSESSMENT EXERCISE

i. Reduction of O_2 and elevation of CO_2 can delay ………………………………. of fresh horticultural crops.
ii. Fruits and vegetables contain between ….. and ….. % water by weight
iii. The moisture content of the stored grain depends on the …………………………………. of the air.
iv. ………………………… is the most important environmental factor which influences the postharvest life of a produce.
v. Temperature and …………………. are determining factors in accelerating or delaying the complex phenomena of the biochemical transformation that are at the origin of grain degradation.

4.0 CONCLUSION

The environmental factors that affect stored products do not exist in isolation; there are defined relationships between many of them. A change in one may lead to changes in another, and may lead to conditions which either promote or prevent spoilage.

5.0 SUMMARY

The environmental factors that influence the post-harvest life of crop produce include temperature, relative humidity, moisture, atmospheric composition and light. Temperature and moisture are determining factors in accelerating or delaying the complex phenomena of the biochemical transformation that are at the origin of grain degradation.

Relative humidity is more useful than absolute measures of humidity for determining the response of living things or biological materials to the air around them. Regulating the gas concentrations in the surrounding atmosphere of the produce is important for reducing respiration and increasing preservation time.

6.0 TUTOR MARKED ASSIGNMENT (TMA)

1. What are the effects of (a) temperature and (b) atmospheric composition on stored agricultural produce?
2. Give the formulae for calculating the moisture content of grains on wet basis and dry basis.
3. Give the recommended moisture content for long-term storage of ten (10) named grains in hot regions.

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UNIT 2 STORE ENVIRONMENT AND TREATMENT

CONTENTS

1.0 INTRODUCTION

In most cases, agricultural products are stored without further handling for a shorter or longer period. Unfortunately losses of 25 percent for stored grain crops and 40-50 percent for vegetables are not unusual in the tropics. For the farmers, these products fulfil various purposes and must be handled properly. For example, if seeds or tubers are not stored well, some will not germinate when planted, which means the farmer will have to plant many more to get enough plants. The seed grains may also grow at different speeds, which will cause problems for cultivating and harvesting the crop. Some insects eat out the best parts of the grain, which contain the vitamins and minerals that make the food nutritious. Farmers may not see this loss, and therefore need to know how to prevent it.

2.0 OBJECTIVES

By the end of studying this unit you should be able to:

- understand the requirements of a good store for the storage of harvested products
- see the need for proper store hygiene and the need for regular store checks
- appreciate the need for and methods of store disinfection

3.1 Store Environment and Treatment

3.3.1 Requirements of store

✓ Keep the temperature and humidity as low as possible through controlled ventilation.

✓ Avoid large variations in temperature, as this can cause condensation of water in the store.

- ✓ Prevent the entry of pests by sealing the store (windows, doors, ventilation facilities) with insect-proof gauze.
- ✓ In conditions with low humidity, airtight storage gives good protection against storage pests.
- ✓ To avoid fungal growth, care should be taken to ensure that the produce stays dry (i.e. no condensation forms inside the container). This is particularly important for long-term storage in warm, dry areas. It is advisable, however, not to store seed for planting for more than a few months. A small amount of seeds can be stored in a strong airtight container with a close-fitting lid (glass, ceramic or strong plastic). Ceramic pots that do not have lids must be covered very carefully or topped up with dry soot, ashes or fine dry soil. In conditions where the relative humidity is high, airtight storage is not recommended due to the risk of fungal growth.
- ✓ The site chosen for a good seed store must be airy, shady, cool and dry.
- ✓ Temperature variations should be as small as possible, because these encourage condensation of water, which in turn promotes fungus development. The whole building should be well aired and if possible fumigated.

3.3.2 Storage Hygiene

- ✓ Always keep the store and its surroundings clean.
- ✓ Before newly harvested crops are stored, the store should be carefully prepared well ahead of time. Old stored products should be removed and the room completely cleaned. The walls, roof and floor should be both watertight and rat proof, and small holes and cracks, which are potential breeding places for storage insects, should be sealed.

3.3.3 Inspecting the store

- ✓ Periodic inspection (weekly to fortnightly) and removal of any infested produce is essential.
- ✓ Check for droppings and footprints of birds and rodents.
- ✓ Look for flying moths at dusk. Brush stacks of bags with a stick or broom to disturb and discover resting moths. Lift bags in order to detect moth cocoons along the line where bags touch each other. When looking for beetles, pay particular attention to cracks, bag seams and ears where they often hide. Empty individual bags in a thin layer onto a sheet and examine the contents for beetles and larvae. This should be done in the shade so that the insects do not flee immediately. Insects can also be sieved out using a box sieve with a mesh of 1-2 mm. Identify the insects found in order to choose the correct treatment.

- ✓ By inspecting in these ways, it should be possible to prevent the breeding of carry-over insects from former crops. The surroundings should also be cleared to discourage easy re-infestation by insects and rodents. Infection with fungi can be detected by the mouldy smell, which is noticeable even before any visual changes to the product can be seen.
- ✓ Pay attention to water marks on bags. They indicate that the crop may have become wet. Even if the bags have dried, the crop can become mouldy.

3.3.4 Store disinfection

After the store has been cleaned completely and all old deposits of dust (that could contain insect eggs) have been removed, it is good practice to dust the whole store with diatomaceous earth, lime or ashes as a further preventive measure. If the wood in the construction has been attacked by larger grain borers, it should be treated with any of the approved wood preservatives or thoroughly sprayed with kerosene or an oil mixture to get rid of any surviving grain borers.

Methods of store disinfection
Mineral substances such as fine sand, clay dust, lime and wood ash can be mixed with seeds, as this causes invisible injuries to food pests, leading eventually to their dehydration. These substances also fill the spaces between the grains, making it difficult for the pests to move and respire. The amounts of these substances required ranges from 50- 100 g per kg of stored product, except for sand, which has to be added in larger amounts.

Wood ash: Mixing seeds with wood ash, either alone or together with powdered chilli pepper, is an efficient method of pest control. However, it does not control the larger grain borer, and ash may have an effect on the taste of the crop. The success of this method depends on the amount of ash added. 2-4 percent ash by weight of grain is said to give 4-6 months protection if the moisture content of the grain is below 11 percent.

Lime: Mixing seeds with 0.3 percent lime (calcium oxide) has given good results in weevil control.

Sand: In areas where fine sand is easily available it can be used to protect stored products. It is best used with bigger seeds, the intention being that all the spaces between the larger seeds should be filled by sand, which can easily be removed by sieving. The more sand used the better, but at least equal amounts of sand and seed should be used.

Diatomite: Diatomaceous earth (DE) is mined in several African countries and can be obtained at a very reasonable price. DE consists of tiny fossil diatoms whose skeletons are made mostly of silica and form the diatomite deposits. DE is a very effective and non-poisonous insect killer. As a dust it can absorb a lot of water, and it kills insects by drying them out. It has been used in South Africa for many years by organic farmers in various kinds of insect control. Farmers using as little as 75 g DE per bag of 25 kg of grain do not experience any problems with weevils and other insects.

Bacillus thuringiensis: Bacillus thuringiensis is a bacterium that is active against insects. In powder form mixed with fine sand it is effective against potato tuber moth. It may be used against grain moths as well.

Vegetable oils: Oils of coconut, castor bean, cottonseed, groundnut, maize, mustard, safflower, neem and soybean affect the egg laying, and egg and larval development of stored pests. Be careful with castor bean oil, because it is very poisonous. Some oils can go rancid during storage and cause crop spoilage. The addition of vegetable oil is particularly useful in protecting legumes against pulse beetles (Bruchids). Losses in pulses can be prevented with the addition of 5 ml oil per kg of grain/seed. To be effective the seed must be fully coated with oil. Sunflower oil is not very effective. The effect of oil treatment decreases with time so seeds stored this way should be treated again at any new sign of infestation. Small seeds may lose some of their germination capacity after oil treatment. If neem seed oil or any other non-food oil is used the bitter taste can be removed by immersing the seed in hot water for a few minutes before food preparation.

Admixture of plant parts: Traditionally many different types of plant parts are used against storage pests.

Table 6.1: Examples of plant materials which help to protect stored seeds/grains

Plant names	**Plant parts**	**Treatment**
Aloe (*Aloe vera*)	Whole plant	Plants dried and ground; dust mixed with the seeds
Chilli peppers (*Capsicum sp*.)	Ripe, dried pods with ashes, dung or fine clay	Whole pods mixed with grain or dusted as powder on beans
Pyrethrum (*Chrysanthemum*	Flower heads Pick on hot days.	Dry in the shade. Crush to powder and mix with seeds

cinerariifolium and C. coccineum)		
Sun hemp (*Crotolaria juncea*)	Seeds	Mix seed between gaps in stored larger size seeds
Datura (thorn apple, *Datura stramonium*)	Leaves and stems (be careful as the seeds are very poisonous)	Dry and mix with produce
Derris (*Derris* sp.)	All parts	Stored produce dusted or sprayed
Eucalyptus (*Eucalyptus* sp.)	Leaves	Layered or mixed with stored produce
Lantana (*Lantana* sp.)	Leaves	Crushed and placed among seeds
Syringa (*Melia Azedarach*)	Leaves, ripe seeds	Dried, powdered, mixed with stored grain using 2% if powder from seed, 4% if powder from leaves
Mexican Marigold (*Tagetes lucida*)	Whole plants	Add dried plants in layers, or mix in powdered plant or place 3-5 cm layer of crushed plants in base of grain bins
Spearmint (*Mentha spicata)*	Whole plant	4% leaf powder will give good protection for more than 4 months
Neem (*Azadirachta indica)*	Leaves, crushed seeds and their extracts and oils	-

The dosages of plant substances required are generally around 50g per kg of stored product. The addition of ash, fine sand, lime, diatomaceous earth, and mineral or vegetable oils is particularly useful for protecting a small storage area or for storing small amounts for replanting. However, this is not always practical for large quantities of seed in terms of labour required. For larger amounts of grains and seeds it is often more practical to simply mix the seed with any strong-smelling plant material available to repel insects. Some plants such as pyrethrum and derris can actually kill storage insects.

SELF-ASSESSMENT EXERCISE

➢ Answer “agree” (A) or “disagree” (D)

A	D	Periodic inspection of crop stores and removal of any infested produce is essential.
A	D	Checking for droppings and footprints of birds and rodents is necessary for crop stores
A	D	Attention should be paid to water marks on bags. They indicate that the crop may have become wet.
A	D	Brush stacks of bags with a stick or broom to disturb and discover resting moths.
A	D	The seeds of datura (*Datura stramonium*) are not poisonous
A	D	Identify any insects found in a crop store in order to choose the correct treatment.

4.0 CONCLUSION

Further handling of agricultural products before storage makes for good quality of the stored products. It is also necessary to pay adequate attention to the details such as the store hygiene, location, management etc.

5.0 SUMMARY

To ensure adequate postharvest storage, proper attention should be given to the facility for storage. This would include keeping the temperature and humidity of the facility as low as possible through controlled ventilation, avoiding large variations in temperature, as this can cause condensation of water in the store, prevent the entry of pests, avoiding fungal growth, etc.

Mineral substances such as fine sand, clay dust, lime and wood ash can be mixed with seeds before storage. This causes invisible injuries to food pests, leading eventually to their dehydration. These substances also fill the spaces between the grains, making it difficult for the pests to move and respire.

6.0 TUTOR MARKED ASSIGNMENT (TMA)

1. Write short notes on:
   a) Methods of store disinfection
   b) Requirements of a building for crop storage

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MODULE 5 PRINCIPLES OF CONTROLLED ENVIRONMENT FOR TRANSIT AND LONG TERM STORAGE

UNIT 1 PRINCIPLES OF CONTROLLED ENVIRONMENT FOR TRANSIT

CONTENTS

1.0 INTRODUCTION

Transportation systems are important in moving fresh produce from production areas to distribution points. Transportation facilitates the rapid movement of fresh produce within the horticultural supply chain. Fresh produce must be properly protected during transportation to minimize mechanical damage, temperature abuse, taint and contamination by foodborne pathogens. It is the responsibility of the transport provider to ensure that the transport vehicle is well maintained and is in a hygienic condition. The quality of perishable products can be adversely affected by a lack of standard hygiene in transportation

2.0 OBJECTIVES

By the end of studying this unit you would be able to:

- have a clear understanding of the factors that affect the quality of products during transportation
- explain hygiene in a transport system
- distinguish the factors that govern the selection of mode of transport
- have an understanding of how to handle the whole sale and retail outlets

3.0 MAIN CONTENT

3.1 Principles of Controlled Environment for Transit

Factors that may compromise quality during transportation

1. **Mechanical damage**
   Mechanical damage of fresh produce results in tissue darkening or colour changes on the skin of the commodity and markedly affects its nutritional and sensory quality, i.e. its taste, texture, appearance and flavour. Mechanical damage can also lead to moisture loss, pathogen invasion and can stimulate the production of ethylene, which triggers the senescence process in horticultural crops such as apples, papayas and tomatoes. The types of mechanical damage that occur during transportation are:
   - **i.** **Impact damage:** Impact damage occurs due to collision between produce items or between produce and hard surfaces; rapid acceleration or deceleration (e.g. when fruits are dropped) or exertion or removal of forces (such as impact, compression, vibration and abrasion) within a short time (duration impact). Impact damage can result in bruising with or without skin injury.
   - ii. **Compression damage:** Compression damage occurs when produce is subjected to heavy commodity weight, with or without physical movement, as occurs when containers are of inappropriate depth, over-packed, packed in containers of poor structural integrity, improperly packed or stacked too high; generally results in distortion cracks and splits; is usually caused by package failure, and is also caused by stacking or sitting on top of produce.
   - **iii.** **Abrasion damage:** Abrasion damage occurs when the surfaces of produce slide across another surface causing friction; can result in removal of the cuticle and wax layers of produce; and can be minimized with the use of lining or padding materials, such as paper or sleeves to protect the produce.
   - **iv.** **Vibration damage:** The level of vibration of a moving vehicle is greatly influenced by the nature of the road and the suspension system of that vehicle. The vibration occurs when produce moves repeatedly for prolonged periods within a container during transport. Vibration can result in damage due to compression, impact and abrasion. Vibration damage can be prevented, or limited, by the following practices:
   - a) Use plastic crates for transportation – vibration damage is less with plastic crates than with cartons since plastic

crates absorb and dissipate the force, thereby keeping the effects of vibration within the crate.

b) Use rigid containers to limit the movement of the base of the container in the transport vehicle.
c) Use a vehicle with a firm suspension system.
d) Use radial tires, which absorb more impact than other types for road transport.
e) Minimizing mechanical damage

Mechanical damage can be minimized through the use of packaging that can withstand the following:

a) Rough handling during loading and unloading;
b) Compression from the overhead weight of other containers;
c) Impact and vibration during transportation
d) High humidity during pre-cooling, transit and storage.

2. Overheating

Overheating occurs as a result of external sources (such as the sun, heat from the road, the walls of the vehicle etc.) as well as from heat generated by the product within the transport vehicle. Overheating causes natural breakdown and decay and increases the rate of water loss from the produce. Overheating can, therefore, result in overall quality loss. Factors that contribute to overheating include:

a) the heat generated by the product due to respiration;
b) lack of ventilation, as occurs in closed vehicles;
c) restricted movement of air between and through packages;
d) lack of adequate ventilation in packaging; and
e) Exposure of packaged products to the sun while waiting to be transported or unloaded.

Overheating can be avoided by:

a) use of well-ventilated vehicles;
b) proper stacking to allow for the disposal of heat;
c) use of well-ventilated packaging;
d) avoidance of exposure to the sun on loading and off-loading tarmacs; and
e) Travelling early in the morning or at night if non-refrigerated transport is used.
f) Loading patterns in transport systems to minimize overheating
g) Stacking patterns in transport vehicles should minimize contact between the produce and the floor and wall surfaces of the vehicle to reduce the transmission of heat from the outside of the vehicle into the loaded produce. Centre-loading leaves an insulating air space between the load and the outside walls of the vehicle.

3. **Build-up of gases in the transport system**
   Inadequate air circulation during the transportation of fresh produce can lead to the build-up of ethylene or carbon dioxide. Care must therefore be taken to assure proper ventilation within the vehicle to avoid gas build-up.
4. **Transportation of mixed loads**
   Mixed loads can be of serious concern when temperature optima are not compatible or when ethylene-producing commodities and ethylene-sensitive commodities are transported together. Wet and dry produce items must be transported in separate mixed loads to avoid the transfer of contamination from wet to dry produce.

Hygiene in transport systems
The quality of perishable products can be adversely affected by a lack of standard hygiene in transportation systems. Soil, typically found in a field, can encrust the floor area of the transport system. To prevent contamination by food-borne pathogens, transport systems should make use of good sanitation practices, ensure proper temperature and humidity management and minimize potential damage to the produce. All vehicles used for transportation of food products must be cleaned and washed routinely to remove decaying remains of agricultural produce. Water, used for washing, must be safe and clean. If pallets are cleaned by fumigation, only recommended/permitted fumigants or chemicals must be used and such use must be according to the manufacturer‘s recommendations.

Factors that govern the selection of the mode of transportation
The mode of transportation is influenced by:
a) The destination of the produce
b) The value of the produce
c) The degree of perishability
d) The volume of products to be transported
e) Recommended storage temperature and relative humidity conditions for the load
f) Ambient temperature conditions at origin and destination points
g) Time in transit to reach the destination by air, land or sea transport
h) Road access
i) Freight rates
j) Quality of the transportation service

Transport equipment
Equipment used for the transport of fresh produce include:

a) Refrigerated and non-refrigerated vehicles – for highway transport
b) Containers for air, rail and highway transport, and for lift-on/lift-off ocean transport
c) Breakbulk refrigerated vessels – for handling palletized loads in the refrigerated holds of vessels
d) Pallets – for air cargo and highway transport
e) Horse carts, donkeys
f) Wheelbarrows and carts – for transportation over distances of 1-8km

SELF-ASSESSMENT EXERCISE

✓ Factors that may compromise quality during transportation, except

a) Mechanical damage
b) Overheating
c) Over speeding
d) Build-up of gases in the transport system
e) Transportation of mixed loads

✓ List the types of mechanical damage that occur during the transportation of harvested fruits and/or vegetables.

4.0 CONCLUSION

Improvements are continually being made in attaining and maintaining the optimal environmental conditions (temperature, RH and concentrations of O_2, CO_2 and C_2H_2) in transport vehicles. Produce is commonly cooled before loading and is loaded with an air space between the palletized produce and the walls of the transport vehicles to improve temperature maintenance. In some cases vehicle and produce temperatures data are transmitted by satellite to the control centre, allowing all the shipments to be continuously monitored. Some new trucks have air ride suspensions, which eliminates vibration damage. As the industry realizes the importance of air rides, their popularity will increase.

5.0 SUMMARY

Equipment used for the transport of fresh produce includes Refrigerated and non-refrigerated vehicles – for highway transport. Refrigerated and non-refrigerated vehicles Refrigerated or non-refrigerated vehicles can be used for the bulk transportation of fresh produce. Non-refrigerated vehicles must provide sufficient cooling of the product during transport. The load should be covered with a white/light-coloured canvas to avoid overheating and to allow adequate air circulation throughout the production. Refrigerated vehicles/trailers must be properly insulated, have a high-capacity refrigeration unit and fan and an air-delivery duct. The vehicle should be well insulated to maintain a cool environment for pre-cooled commodities and adequately ventilated to allow air movement through the produce.

6.0 TUTOR MARKED ASSESSMENT (TMA)

1. List the four types of mechanical damage that occur during transportation
2. Describe the factors that contribute to overheating in a vehicle transporting crop produce
3. Explain how overheating can be avoided in a vehicle transporting fresh produce
4. List the equipment used in the transportation of fresh produce.

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UNIT 2 PRINCIPLES OF CONTROLLED ENVIRONMENT FOR LONG TERM STORAGE

CONTENTS

1.0 INTRODUCTION

Consumers are increasingly demanding a year-round supply of high-quality fruit and vegetables and this demand has been met in part by the use of refrigerated storage. However, the development of controlled atmosphere (CA) and modified atmosphere (MA) storage offers further opportunities for extending the storage life of seasonal perishable produce, when refrigeration alone is not sufficient.

2.0 OBJECTIVES

By the end of studying this unit you would be able to:

- define Modified atmosphere (MA) storage
- understand the most commonly used systems of controlled atmosphere storage.
- know the technical problems that hindered the use of CA transportation in the past.

3.0 MAIN CONTENT

3.1 Principles of Controlled Environment for Long Term Storage Controlled atmosphere (CA) and modified atmosphere (MA) storage

While there is no formal definition of CA storage, it can be assumed to be the control of the levels of certain gases around, and therefore within, fresh fruits and vegetables. Controlled atmosphere storage supplements cold storage and is only successful when applied at low temperatures. Standard refrigeration units are therefore integral components of controlled atmosphere stores. The extended storage life of produce is

achieved by reducing the respiration rate, browning reactions, sprouting, softening and decay of fruit and vegetables.
Modified atmosphere (MA) storage (or modified atmosphere packaging (MAP), on the other hand, is a condition where the fruit or vegetable is enclosed within a sealed plastic film, which is slowly permeable to the respiratory gases. The gases will change within the package, thus producing lower concentrations of oxygen and higher concentrations of carbon dioxide than exist in the fresh air. The modified atmosphere may also be defined as 'an atmosphere of the required composition created by respiration, or mixed and flushed into the product enclosure'.

Although the precise details of how CA and MA work are not fully understood and are the subject of continuing research, it is accepted that the effects that varying the levels of oxygen and carbon dioxide in the atmosphere have on crops will vary with factors such as the crop species and cultivar; the growing conditions before harvest; the degree of ripeness of the climacteric fruit; the concentration of the gases in the store or package; the crop temperature; and the presence of ethylene in the store.

There are also interactive effects of the two gases, so that the effect of the carbon dioxide and oxygen in extending the storage life of a crop may be increased when they are combined. Moreover, as well as maintaining the postharvest quality and extending the shelf-life of produce, CA and MA are also beneficial in reducing or eliminating insect and pathogen damage during transit and storage – this is particularly important as consumers demand fewer chemicals in food crops.

While the technical benefits of CA and MA storage have been demonstrated for a wide range of fruit and vegetables, the economic implications of using this comparatively expensive technology have often limited commercial application. However, with technological developments, more precise control equipment and the reducing cost, the technology is finding a wider commercial use for an increasing range of crops. There are different types of CA storage depending mainly on the method or degree of control of the gases. The two most commonly used systems are:

Static CA storage: where the product generates the atmosphere; and
Flushed CA storage: where the atmosphere is supplied from a flowing gas stream that purges the store continuously.

While CA technology has largely focused on the long term storage of bulk fruit and vegetables, more recently both CA and MA have been applied to the short-term storage of certain commodities. These include some high-value crops where limited production in locations distant from consumption areas justify the use of CA and MA to extend storability, and some lightly processed fruits and vegetables (e.g. chopped and shredded lettuce, sliced and shredded carrots and sliced celery, cucumbers, radishes and green peppers). In most cases, perishable commodities are stored under constant conditions, especially at low temperatures. However, even under these conditions, the commodity is experiencing physiological and metabolic changes. For this reason, researchers are looking at the storage process as a dynamic system and the use of flexible control rather than constant-value systems to obtain a qualitative improvement. Studies have looked at neural networks and genetic algorithms for realizing the optimal control of fruit storage. Optimum storage conditions for fruit and vegetables depend upon several factors, including the cultivar, stage of maturity at harvest and growing conditions.

Total nitrogen or high nitrogen storage

The storage of some fruits in total nitrogen or nitrogen-rich atmospheres can be beneficial. Ripening of plums stored in total nitrogen has been reported to be almost completely inhibited (Anon. 1920). Plums were able to tolerate, for a considerable period, an almost complete absence of oxygen without being killed or developing an alcoholic or unpleasant flavour. For strawberries, 100% and 99% nitrogen atmospheres reduce mould growth during 10 days of storage at 1.1℃ with little or no effect on flavour (Parsons *et al*. 1964). Similarly, for peaches, decay was reduced during storage in either 100% or 99% nitrogen at 60°F; off-flavours were detected in fruit after 4 days in 100% nitrogen, but none in those stored in 99% nitrogen.

Controlled atmosphere transport

Large quantities of fresh fruit and vegetables are transported by sea-freight refrigerated (reefer) containers. It was estimated that the world fleet increased four-fold from 1993 to 1997 when there were around 38000 reefer containers. Relatively small but increasing numbers of containers (approximately 1000 containers) are being used for the CA transportation of fresh fruit and vegetables. These commodities include apples, apricots, asparagus, avocados, bananas, broccoli, cantaloupes, cauliflowers, cherries, eggplants, kiwifruit, limes, mangoes, peaches, nectarines, pears, pineapples, plums, sweetcorn and tomatoes.

Several technical problems hindering the use of CA transportation in the past (the lack of gas-tight containers, suitable systems for gas control and analysis, and adequate CA-generating systems) have now largely been overcome. A common problem was the maintenance of gas-tight conditions. The leakage from some early systems was as much as 5m3 h–1, but leakage from current systems can be below 1 m3 h–1

(Garrett 1992). Much of this leakage is through the door (Thompson 1998) and can be reduced by the use of plastic curtains inside the door. However, these curtains are difficult to fit and maintain under working conditions. A system introduced in 1993 had a single door instead of the double doors of reefer containers and was easier to make gas-tight.
There are several commercial systems available and these can be broadly classified as either CA or MA systems. The latter requires the injection of an appropriate mixture of gases into the sealed container at the beginning of the journey with no subsequent control, so the atmosphere will constantly change during transport. Controlled atmosphere containers have a mechanism for measuring the changes in gases and adjusting them to a pre-set level. Standard reefer containers can be converted to CA containers either permanently or temporarily. The systems used to generate the atmosphere in the containers fall into three categories:

Category i: The gases can be carried in a compressed liquid form in steel cylinders at the front of the container, with access from the outside. This system involves injecting nitrogen into the container to reduce the level of oxygen. Oxygen levels are maintained by the injection of nitrogen if the leakage into the container is greater than the utilization of oxygen through respiration by the stored crop. If the respiration of the crop is high the oxygen can be replenished by ventilation.

Category ii: Membrane technology may be used to generate the gases by separation. The carbon dioxide is generated by the respiration of the crop and nitrogen is injected to reduce the oxygen level. Nitrogen is produced by passing the air through fine porous tubes, made from polysulphones or polyamides, at a pressure of about 5–6 bar. These will divert most of the oxygen through the tube walls, leaving mainly nitrogen which is injected into the container.

Category iii: The gases can be generated in the container and recycled with pressure absorption technology and swing absorption technology. This system uses ventilation to control oxygen levels and a molecular sieve to control carbon dioxide.

Modified atmosphere packaging
Modified atmosphere packaging (MAP) involves the sealing of commodities in plastic films so that the composition of gases of respiration and transpiration in and around the product is altered. For fresh fruits and vegetables, this is commonly achieved by wrapping individual items, boxes of produce or a pallet of boxes in a plastic film. The films can be slowly permeable to carbon dioxide, oxygen and other gases, even water vapour, depending on their thickness and composition.

Modified atmosphere packaging has been known for several decades to have great potential in extending the post-harvest life of several fruits and vegetables. Modified atmosphere packaging is also advantageous in maintaining some minimally processed tropical fruits such as durian, jackfruit, mangosteen, papaya and pineapple. However, overall, reported results for MAP are very variable and thought to be due to a lack of experimental control. Some of the reported beneficial effects of MA may be due to maintaining a humid atmosphere around the commodity, and not to gas modification. Modified atmosphere packaging works by slowing down the deterioration of the 'fresh-cut' or minimally processed fruit and vegetables.

The potential advantages and disadvantages of MAP are summarized in Table 5.20.

Gases used in MAP

The three main gases used commercially in MAP are oxygen, carbon dioxide and nitrogen (nitrogen is used as a filler gas to prevent pack collapse, which may occur in atmospheres containing high carbon dioxide). Recently, there has been some interest in the potential applications for the use of novel gas mixtures (e.g. argon and nitrous oxide), although these are largely at the experimental stage. The gases and their concentrations should be tailored for each product (specific variety). The modified atmosphere may be produced naturally by respiration (passive MA) and by the application of gas flushing techniques (equilibrium MA).

SELF-ASSESSMENT EXERCISE

Consumers are increasingly demanding a year-round supply of high-quality fruit and vegetables and this demand has been met in part by the use of refrigerated storage. **True/False**

i. The three main gases used commercially in modified atmosphere packaging (MAP) are oxygen, carbon dioxide and carbon monoxide. **True/False**
ii. Controlled atmosphere storage supplements cold storage and is only successful when applied at high temperatures. **True/False**

4.0 CONCLUSION

The development of a controlled environment for storage offers further opportunities for extending the storage life of seasonal perishable produce However, while the technical benefits of a controlled environment for storage have been demonstrated for a wide range of fruit and vegetables, the economic implications of using this comparatively expensive technology have often limited commercial application. With technological developments, more precise control equipment and the reducing cost, the technology is finding a wider commercial use for an increasing range of crops.

5.0 SUMMARY

Controlled atmosphere storage supplements cold storage and is only successful when applied at low temperatures. Although the precise details of how controlled atmosphere and modified atmosphere work are not fully understood and are the subject of continuing research, it is accepted that the effects that varying the levels of oxygen and carbon dioxide in the atmosphere have on crops will vary with factors such as the crop species and cultivar; the growing conditions before harvest; the degree of ripeness of the climacteric fruit; the concentration of the gases in the store or package; the crop temperature; and the presence of ethylene in the store.

6.0 TUTOR MARKED ASSIGNMENT (TMA)

1. Define Modified atmosphere (MA) storage
2. Name the two most commonly used systems of controlled atmosphere storage.
3. Enumerate thee (3) technical problems that hindered the use of CA transportation in the past.

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MODULE 6 OPERATIONAL EQUIPMENT FOR STORAGE AND PRESERVATION

UNIT 1 STORAGE STRUCTURES/METHODS

CONTENTS

1.0 INTRODUCTION

The primary objective of storage is to maintain the quality of the commodity from the time of loading for as long as is required. In practice, many commodities will begin to deteriorate after harvest and so the objective of storage will be to minimize the rate of deterioration. This is achieved by providing protection against external elements (including temperature and humidity as well as pests such as rodents, birds and theft by man) and protection against the products of respiration of the commodity (heat, moisture, and gases such as carbon dioxide and ethylene). There is no single, ideal design of the store. This will be determined by the particular storage requirements of the commodity and the potential for loss.

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

Traditional Structures: Small-sized and short term with a 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.

2.0 OBJECTIVES

By the end of studying this unit you would be able to:

- describe various types/methods of storage structures used for storing agricultural produce
- know the essential features to look out for when using ventilated structures for the storage of fresh fruits and vegetables.

3.0 MAIN CONTENT

3.1 Storage Structures/Methods

3.3.1 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 a low level of scientific knowledge to construct, operate and maintain. They are mostly made of unrefined local materials. More than three-quarters of the agricultural output of African smallholder farmers are kept at the village level for local use and stored using traditional methods. Storage at the household level offers several advantages, including the following:

i. It stores food close to the majority consumer
ii. It gives farmers easy access to their assets and facilitates sale transactions
iii. It does away with transport and handling costs and eliminates losses that occur at this level.
iv. It serves as a source of information regarding the supply of grain on the market which informs production decisions. If the household storage is still full when farming preparations are underway, this might signal that there is still an oversupply of the type of grain on the market. An informed farmer may reduce his acreage from the oversupplied grain to another crop.

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

Traditional storage structures/methods include:

i. Aerial storage
ii. Storage on the ground
iii. Domestic structures
iv. Barn, Shelf and Pit/ Underground Storage
v. Timber platforms and frames
vi. Traditional Cribs
vii. Ventilated structures for perishable crops
viii. Mud silos (Rhombus)
ix. Drums
x. Solid walled bins
xi. Metal bins

i. Aerial storage

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

ii. Storage on the ground

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

iii. Domestic structures

This is the family level storage practised in a household. Some of the facilities used for domestic storage include guards, tin, box, basket, jute bag, polythene bag, an earthen pot, plastic or metal containers. It is advisable to cover the tin used for domestic storage of grains. The open end of the 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 foodstuff with chemicals.

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

iv. **Barn, shelf and pit**: These are among the most common and oldest methods of storage. They are mostly used for root and tuber crops. Barn and shelf could be suitable for onion and carrot. The barn protects the produce from bad weather, rodents and insect pests. Yam barns are common among traditional yam farmers of West Africa. The barns consist of timber racks supported on a frame of vertically erected posts about 3m high and set about 50cm apart. Horizontal bars are attached to the posts to stabilize them. Sometimes, use is made of growing trees as uprights as they strengthen the structure and the foliage can provide natural shade. Where trees cannot be incorporated into the structure, the barn is provided with a roof. Siting the barn to ensure maximum ventilation is important.

Yams stored in traditional barns may be vulnerable to attack by rodents or even domestic animals. Attempts are therefore made to exclude animals by surrounding the barn with a fence. Alternatively, yams may be stored on simple shelving systems with rodent guards fitted to the legs.

The traditional yam barn is a framework of vertically arranged wooden poles. The poles are arranged at about 50cm apart and may be held together by more rigid horizontal wooden sticks for stability. The spacing between the columns is selected such that when the tubers are put in place, they form a closed wall but with a provision made for entrance. Yam tubers are fastened individually to the poles through strings or other local cordage materials such as raffia. The shape of the barn could be circular or rectangular depending on the owner's interest. Shades are always provided for the barn using spear grass, palm fronds and leaves, raffia palm or banana leaves. The materials for the barn construction are usually gotten from the immediate environment and the skill needed for construction and placement of the tubers is simple. In some situations, the shaded enclosure within the barns provides a good storage environment and yam tubers are placed on the floors. These are mostly used for root and tuber crops. Barn and shelf could be suitable for onion & carrot. Barn, shelf and pit are recommended for cassava, yam and cocoyam. They are affected by environmental conditions.

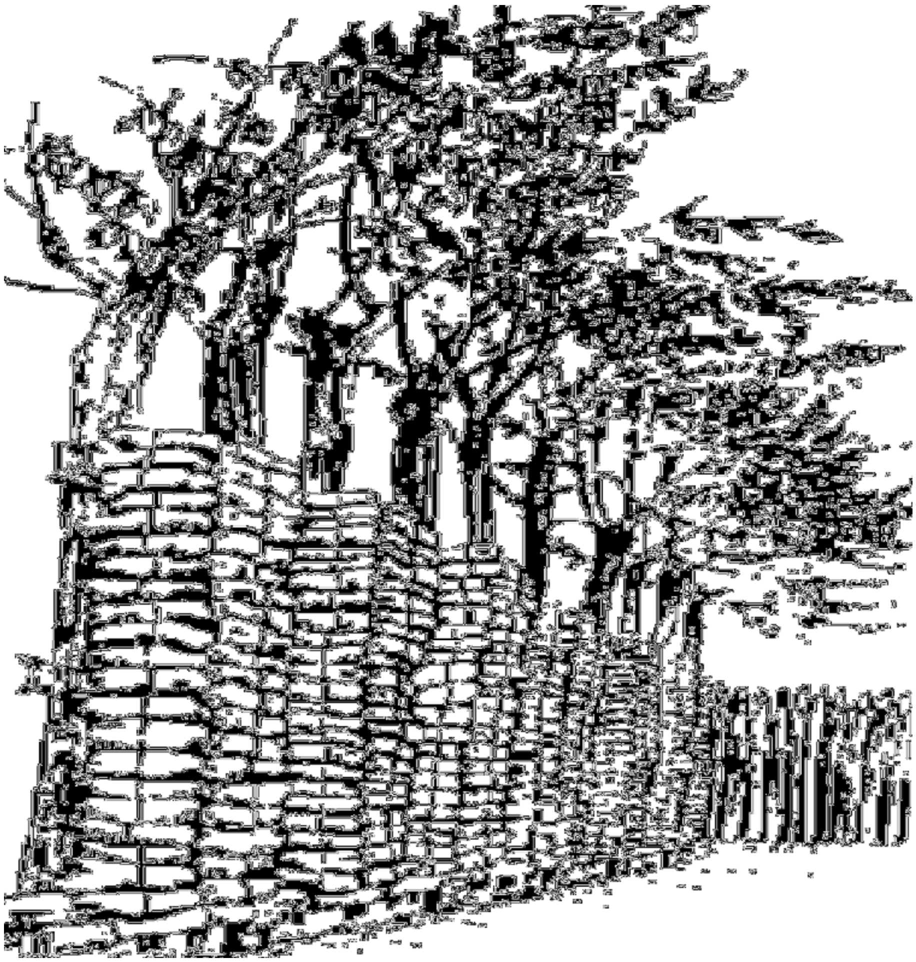

Fig.1: Yam barn (use is made of growing trees)

Fig. 2: Yam barn (use is made of constructed poles)

Fig. 3: Yam shelf

Pit storage is an ancient method of grain storage and is still in some countries. Pit stores used by farmers may have capacities ranging from less than 1 ton to more than 20 tons. The shape of pits vary from region to region; they may be straight-sided, square, cylindrical, spherical or amphoric in shape. The entrance to the pit may be closed with a large stone or strips of wood, covered by a layer of soil.

An absorbent lining to the pit made from grass matting and straw, or chaff and grain husks, will help to reduce the damage from moisture that might seep through the walls of the pit. Improvements to traditional pits have addressed the problem of moisture penetration, mixing of soil and grain and subsequent mould damage. A plaster lining made from a mixture of mud and cow dung, or a single concrete lining, will restrict the ingress of water and termites as well as prevent the intermixing of soil with grain.

More sophisticated concrete or ferrocement linings are built up in several layers and incorporate bitumen or other waterproof coatings. Lining pits with plastic sheets also helps to restrict moisture damage to the stored grain. In underground storage, the entire store can be concealed so the grain is unlikely to be stolen and there is no risk of fire. Well-sealed pits will prevent entry by grain insect pests. Some initial mould growth is likely but this may reduce oxygen levels which in turn can asphyxiate insects and inhibit further mould growth. Termites sometimes damage grain stored in pits and burrowing rodents can occasionally gain access to the stored grain. Underground storage may also be used for relatively short periods for yams and potatoes. For example, if labour at harvest time is limited, yams may be held temporarily in trenches or pits dug in or close to the field. The pits are usually lined with straw and the tubers are stored on a layer of straw either horizontally on top of each other or with the tip vertically downwards beside each other.

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 sawdust. Pit storage conserves the moisture of the stored products. It is advisable to store cassava in the pit with its stem. Bruised tubers and cassava must not be stored in a pit. Underground storage is a short-term measure, as tuber crops are highly perishable. The following considerations must be made:

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

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

- (1) The construction involves the excavation and removal of soil from the proposed pit location. The sides of the pit could be vertical or sloped depending on the soil stability and the shape desired.
- (2) The walls and floor of the pit are treated with non-toxic chemicals as protection against insects and other soil residing organisms. This treatment is important even if there is no sign of the presence of any insects at the construction stage, the produce to be stored later would provide a good host to which insects would be attracted. The chemical must be thoroughly sprayed all over the floor and walls and in sufficient quantity to ensure adequate penetration into the soil.
- (3) The floor and walls of the pit are then lined with a suitable material which could be straw, mats, plastic sheets and bags, concrete and bitumen, stones, bricks, gravels and wood to prevent the walls from caving in. The use of

plastic materials, bitumen and concrete results in moisture-tight pits and excludes ground moisture entry, inhibit the penetration of microorganisms into the produce stored. The use of straw however does not provide moisture tight structure.

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

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

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

Fig. 4: Pit storage

v. **Timber platforms and frames**

Platforms and frames can be made at a minimal cost from local materials and may be used for the storage and drying of produce. Platforms constructed in the open may be four-cornered or circular racks, usually raised about 2m above the ground. The grain may be placed on the platform soon after harvest and a fire may be lit under the platform to facilitate drying and to deter insects and other pests. Platforms may be covered with a thatch roof that can be lifted off from time to time to aid drying or to remove produce. In humid areas, husked maize on the cob may be stacked in layers to form a cylindrical stack which is then covered with a cone-shaped roof. Cone-shaped, rather than flat platforms are common in humid areas and facilitate drying. Platforms or racks may also be constructed inside the house, often over the cooking fire, or to provide a storage loft below the roof. The practice of gathering harvested crops at strategic locations on the field while the harvesting operation is in progress and for such gatherings to be conveyed eventually to the central farm store either at the end of the daily or entire harvest operation is common practice with peasant agriculture. To further reduce the moisture content of the harvested produce for effective storage, the small produce pilings scattered all over the field are often left in place for weeks before being collected to the central farm store.

Frames consisting of narrow timber or bamboo poles fixed horizontally to heavy upright poles embedded in the ground may be used for storage of maize cobs or sorghum heads, but their main purpose is to facilitate drying of the crop. Platforms and frames may be improved by fitting rodent barriers around the supporting posts to protect them against rodents. To provide some protection against termites, the posts should be coated with bitumen or used engine oil.

Fig. 5: Timber platform frame

vi. Traditional Cribs: Cribs are used for storing cereals especially maize and guinea corn during the dry season. Cribs are built from local wooden materials in a rectangular or cylindrical shape, and a thatch roof. They are produced with adequate ventilation and this helps to dry up the cobs.

In humid countries, where grain cannot be dried thoroughly before storage and needs to be ventilated, traditional cribs are used. These are circular or rectangular structures with a framework of wooden poles, with a roof of thatch or corrugated iron sheets. The walls may be made of raffia, bamboo, poles, sawn timber or wire netting and should allow good ventilation and drying. Grain dries best in a narrow crib and, ideally, it should be between 0.5m and 1.5m wide and erected in the open, with the long side across the prevailing wind. The floor of the crib should be at least 0.7m above the ground and the legs should be fitted with rodent guards and treated as necessary to protect against termite attacks.

Cribs provide flexibility in use. They are primarily intended for drying produce, especially maize on the cob. However, they may be used for storage of shelled maize in bags after drying is complete, but in this case, the walls should be covered to protect driving rain. They may also be modified for storing other commodities such as root crops and onions. Traditional cribs usually require a high level of maintenance and may have to be replaced completely after 2–5 years. Improved cribs made from sawn timber, wire netting and metal roof sheets may last for 10–15 years. The quality of grain stored in cribs will be influenced by the local climate, the presence of pest infestation, design and construction, and the variety of grain being stored. It will usually be necessary to treat stored maize cobs of high-yielding varieties with an insecticide at the time of storing.

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

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

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Fig. 6: Storage Crip

vii. Ventilated structures for perishable crops

Ventilated structures such as cribs can be used for the storage of products with long storage potentials such as roots, tubers, and onions. The following essential features should be observed:

a) The structure should be located at a site where low nighttime temperatures prevail over the storage period;
b) If the structure is subject to cold night-time temperatures, movable louvres should be fitted and adjusted to limit the flow of warm air into the structure during the day;
c) The structure should be oriented to make maximum use of the prevailing wind for ventilation;
d) Ventilation spaces below the floor and between walls and roof should be provided to encourage good airflow;
e) The roofing material should provide insulation, and the roof should extend to shade the walls of the structure;
f) Double walls will provide better insulation; and
g) External walls painted white will reflect the heat of the sun.

viii. Mud silos ("Rhombus"): This storage involves structures designed and constructed locally for storing (mostly un-threshed) grains like maize, millet and sorghum especially in the Northern part of Nigeria. Sometimes, heat is introduced at the base to ensure drying. The main disadvantages of rhumba are moisture build as a result of rain, and microorganism infestation.

Sometimes coal or wood heat is introduced at the lower base to ensure drying.

Fig. 7: Mud silos (“Rhombus”)

ix. Bag storage

Bag storage is a convenient way of keeping threshed grain and pulses. Bags provide the flexibility to store different types and different quantities of grains and pulses and the commodity can easily be removed for consumption, inspection or sun-drying. It is also immediately available for sale. Storage capacity is limited only by the number of bags available and the size of the storeroom.

Small numbers of bags may be kept in the house or a separate storeroom. Ideally, bags should be raised off the floor or on storage platforms to prevent them from getting wet from the uptake of moisture from the ground. Successful bag storage depends on the adoption of good storage management, especially as they provide little protection against insects, rodents and moisture.

Fig. 8: Bag storage

x. **Drums:** Small grains can be stored in air-tight drums bins and sealed up. This kills insects that may be present in the grains. Sometimes, chemicals and compounds are added to preserve the content. It is very important to keep the drums out of the sun, otherwise the hot sun hitting (especially) the metal drum will make the grain very hot, sweat and respire faster thereby causing spoilage.

xi. **Solid wall bins**

Solid wall bins are often associated with dry climatic conditions under which products can be dried satisfactorily by simple sun-drying. The bins may be made of clay plaster, clay blocks, stones or burnt bricks and are raised off the ground on timber frames, on large stones or a clay pedestal, improved solid wall bins made of stones or bricks may have a concrete pedestal or foundation incorporating a moisture-proof barrier to prevent uptake of moisture. The structures may be round, cylindrical or rectangular in shape and designs are often characteristic of communities or localities. The clay used for the construction of solid wall bins commonly comes from termite mounds and is strengthened by the addition of straw. Thin-walled structures are often used for the storage of unthreshed grain and pulses whereas the stronger, thick-walled structures are more suitable for storage of threshed grain and dried root crops such as dried cassava chips.

A modified mud-walled bin with a thatch roof may be used for the storage of yams. These structures, which resemble small mud huts since they are provided with a door or opening, are to be found in the savannah areas of the Yam Belt in West Africa.

Good protection is provided against direct sunlight and rain. However, as yams are piled on top of each other, ventilation is restricted and the development of rot in the tubers can be a serious problem.

Some solid wall bins have internal dividing walls making several compartments, thus giving some flexibility in the different types or quantities of grain that can be stored. Separate openings for filling and emptying are usually included at the top and bottom of the structures. They may be sited under a shelter or be fitted with a thatch roof to protect against rain and shade from the sun.

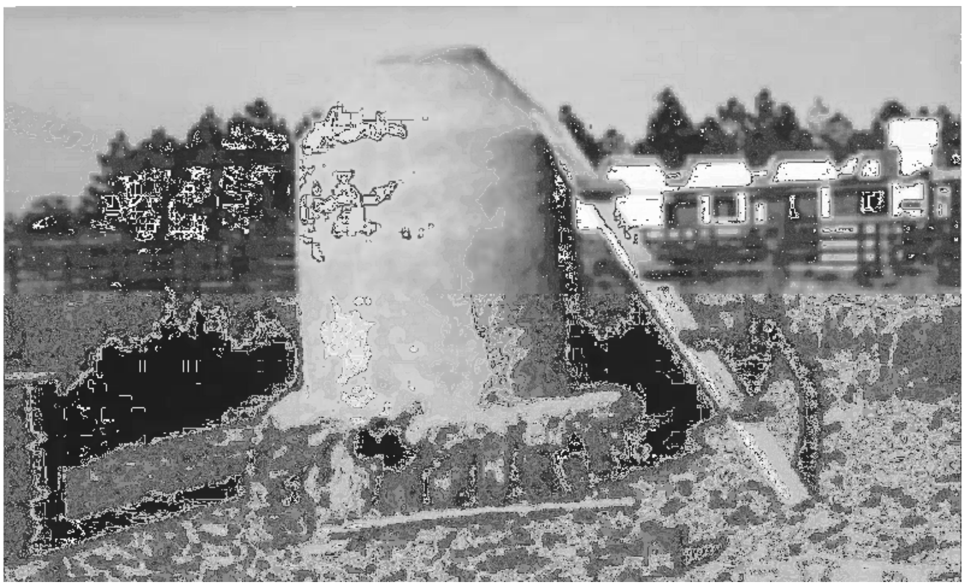

Fig. Fig. 9: Solid wall bin

xii. Metal storage bins

Metal storage bins may be made from flat or corrugated galvanised metal sheets. They are usually cylindrical in shape with a flat top and bottom. Most bins used for small-farm storage have capacities of around 1tonne.

Grain is commonly loaded through a hatch on the top and removed from an outlet in the side or at the bottom of the bin. Bins should be raised off the ground on a platform to allow air to circulate the base to prevent corrosion by ground moisture. They should also be kept in the house or placed under a roof to protect against rain and, more particularly, shade to help reduce moisture migration and heating of the grain inside.

The durability and security offered by the system will appeal to the more affluent farmers. Adoption of metal grain bins is more likely in areas where metal containers are already used as water tanks and they can be made locally by sheet metal workers. Large bins are difficult and expensive to transport to rural areas and are easily damaged in transit over rural roads. Grain must be very dry for storage in metal bins and so the system is more suited to areas where grain is harvested in a distinct dry season, followed by storage through a rainy season where good protection is desirable. Well constructed and well-sealed metal bins will provide good protection against insects, rodents and birds, and mould if the grain is properly dried. Insect control using insecticides or fumigants is essential. The metal bin is one of the most suitable structures for fumigation

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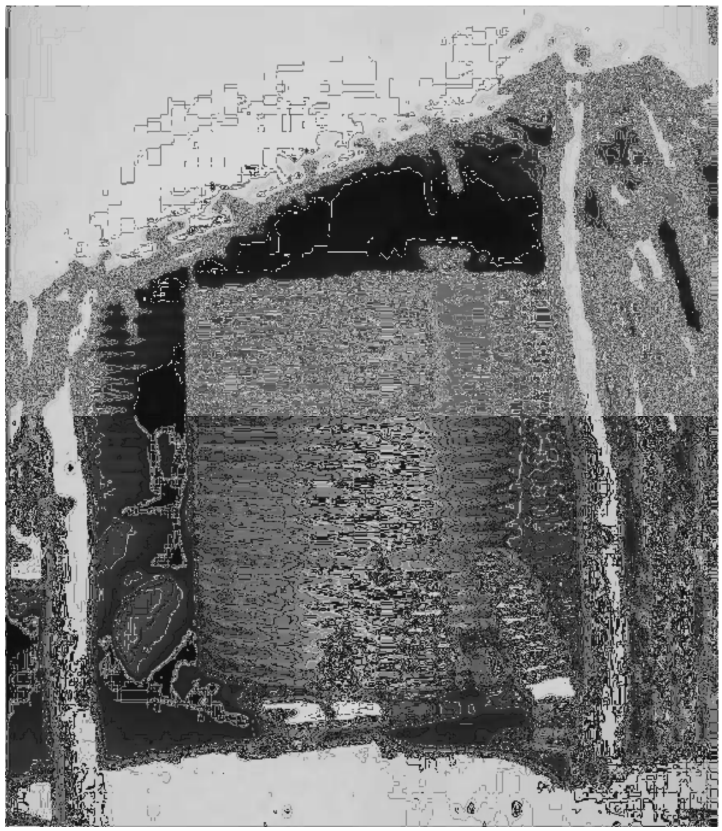

Fig. 10: Metal bin

Modern Storage Structures

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

i. Improved crib
ii. Warehouse
iii. Silo/ Bin
iv. A controlled atmosphere storage system
v. Refrigeration
vi. Cold storage
vii. Evaporative coolant system (ECS)
viii. Hermetic and nitrogen storage systems
ix. Canning

i. 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 crops 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 rainy 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 the product from being contaminated with dust and particulate material. Moisture build is also reduced during the rainy season. This crib is however still experimental. However, it has not being commercialized.

ii. Warehouse

The warehouse is used for medium but mostly large scale storage for bagged or pilled/ bulk products such as grains, flour, etc. Wooden pallets are used for staking. Material handling and ventilation equipment are essential. Prevention of roof leakage and water infiltration through the floor are most essential. Waterproof materials are used for flooring & proper drainage is important. Bagged products are normally stored in the warehouse. Occasionally, bulk materials are also stored in the warehouse.

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Fig. 11: Modern Warehouse

iii. Silo/ Bin

This method is more scientific and expensive. Silos are structures used for bulk storage of shelled grains on a large scale and for a long time. Silo is a cylindrically shaped structure used for bulk storage of shelled grains on a large scale and the long term. Moisture migration and condensation are major problems of the silo. Hence, the need for accessories such as material handling and drying equipment. Design, operation and maintenance of silos require a high level of skill and 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 temperate regions for decades. Most silos are cylindrical in shape and constructed of metal, aluminium, rubber or concrete. Moisture migration and moisture condensation are the major problems militating against the use of silo storage in the tropics. Approaches to solving these problems include the provision of auger agitator and dryer; using of nitrogen atmosphere, airtight, and the introduction of insulations. Material handling equipment is accessories to silo storage. Silo is very costly. Some of them are monitored by computers

Large round silo complexes

These usually comprise at least two rows of round silos, with star-shaped cells in the spaces between the larger main cells. They are often constructed from concrete and are generally of high capacity, often of several thousands of tons. Loading, unloading and conditioning systems are controlled from a centrally located control room. Grain drying may be done in the silo cells themselves or using free-standing high capacity continuous flow driers.

Free-standing, corrugated metal round silos

These are constructed from corrugated sheets bolted to either an internal or an external framework. Ventilation may be achieved using either above or below floor lateral ducts or a fully ventilated floor supported approximately 0.5m above the base.

Fig. 12: Silos

Fig. 13: Silo complex

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

Factors Considered in Silo Design

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

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

Silo Classification

There are different types of a silo. The silo can be classified based on:

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

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

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

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

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

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

- ✓ Conventional silo
- ✓ Instrumentalized silo
- ✓ Computerized/ automated silo

Based on structural stability, the silo can be classified as:

- ✓ Deep silo
- ✓ Shallow silo

iv. Controlled Atmosphere (CA)

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

Fig. 14: Controlled Atmosphere

v. 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 a condenser, evaporator, compressor, throttle pipes, fan, thermostat, etc. It is used for the storage of highly perishable crop and food materials

vi. 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 the temperature below the freezing point for a long time. It has similar components to the refrigerator but is more bulky, expensive and could store for a relatively long time. It is recommended for a 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:

(a) It retards respiration and other metabolic activities.
(b) It controls ripening and retards ageing softening, texture and colour change.
(c) It preserves colour and texture.
(d) It retards moisture loss and wilting.
(e) It controls microbial activities and spoilage.
(f) It retards spoiling and other undesirable growths.

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

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

The factors that affect the performance of cold storage include:

(a) Temperature of Storage: Temperature in cold storage must be uniform within the chambers for uniform ripening. The constant temperature must be maintained. Temperature variation must be minimized to prevent spoilage. For temperature-sensitive products, permissible temperature variation is ±0.5oC while for non-sensitive temperature products, the permissible value is ±1.5oC.

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

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

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

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

(a) Temperature fluctuations affect temperature-sensitive crops. Therefore, keep temperature and storage condition steady and constant

(b) Pre cool fruits to remove field heat before products are transferred into a cold store

(c) Avoid storing incompatible products

(d) Ensure adequate ventilation within a cold store and use appropriate relative humidity

vii. Evaporative Coolant System

An 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 wet material to produce cooling inside. Wetted padded materials are normally used as a medium of evaporation

viii. Hermetic and Nitrogen Storage Systems

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

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

ix. Canning

This involves the storage of food items under hygienic conditions in air-tight cans and tins. In canning, the containers are first cleaned and sterilized by heating them in boiling water. Canning helps in keeping away bacteria, unwanted enzymes and oxygen that can destroy the produce. Preservatives may be added. Examples of items stored by canning include fish, meat, fruit, tomatoes and dairy products.

SELF-ASSESSMENT EXERCISE

List five (5) traditional and five (5) modern storage structures and discuss any two (2) of each**.**

4.0 CONCLUSION

There is no single, ideal design of the store. The design of the store is determined by the particular storage requirements of the commodity and the potential for loss.

5.0 SUMMARY

One major objective of storage will be to minimize the rate of deterioration. This is achieved by providing protection against external elements (including temperature and humidity as well as pests such as rodents, birds and theft by man) and protection against the products of respiration of the commodity (heat, moisture, and gases such as carbon dioxide and ethylene).

6.0 TUTOR MARKED ASSIGNMENT (TMA)

a. Write short notes on silos
b. For storage in metal bins, the system is more suited to areas where grain is harvested in a distinct dry season. Why?
c. List five (5) types/methods of storage structures used for storing agricultural produce and discuss any two (2) of them.
d. What are the essential features to look out for when using ventilated structures for the storage of fresh fruits and vegetables?

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UNIT 2 WAREHOUSE/EQUIPMENT MANAGEMENT

CONTENTS

1.0 INTRODUCTION

Storerooms, warehouses and distribution vehicles should be constructed to prevent access by rodents, insects and birds, and carefully inspected regularly to ensure that preventative measures are effective. There must be a high level of control over hygiene and storage conditions in warehouses and distribution vehicles to that given to processing operations. When equipment is checked carefully, small problems can be identified and corrected before they cause downtime next season. Proper off-season checks will add value to farm equipment, increase its lifespan and decrease operating costs.

2.0 OBJECTIVES

By the end of studying this unit you would be able to:

- understand the main causes of spoilage of stored foods and ingredients
- know the reasons for food packaging
- appreciate why warehouses should be encouraged to be computerized
- develop a checklist that could be used to identify and solve problems of storage equipment:

3.0 MAIN CONTENT

3.1 Warehouse/Equipment Management

3.3.1 General Considerations

Modern warehouses are provided with material handling equipment especially when bulk materials are stored. Leaking roofs and cracked walls must not be allowed in the warehouse. Bagged products are properly stacked on wooden platforms. The 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 the warehouse must be well above the ground level to prevent flooding and a solid foundation must be provided. Waterproof materials could be constituents of the foundation. This is to prevent water seepage. The floor should be provided with proper drainage.

Windows should be screened against insects, drainage channels and power cable ducting are fitted with devices to prevent entry by rodents, the structure of the roof and walls is designed to prevent insects, rodents and birds from gaining entry. Doors are fitted with screens or air curtains and rooms are equipped with insect electrocution. Floors are covered with vinyl-based coatings to prevent cracks that could harbour insects and micro-organisms.

The main causes of spoilage of stored foods and ingredients are as follows:

a) Contamination by rodents, birds, insects and micro-organisms
b) Contamination by dust or foreign bodies
c) Respiratory activity of fresh foods, or enzyme activity leading to the development of rancidity or browning
d) Losses from spillage, bursting of containers, etc.
e) Incorrect storage conditions such as exposure to sunlight, heat and moisture.

Most foods are packaged for the protection and convenience of handling. Packages that are grouped into larger (or 'unitised') loads require less handling when they are moved through storage and distribution networks. Wooden pallets are commonly used to move unitised loads of cases or sacks by fork-lift or stacker trucks.

Working procedures in storerooms and warehouses ensure that sacks or cartons of food are stored on pallets or racks to keep them off the floor, with space to clean behind the stack. They should be carefully stacked to the recommended height to prevent crushing or collapse and injury to operators. Lighting should be as bright as possible and at a high level to reduce shadowing caused by stacked pallets.

Warehouse management systems are increasingly computer-controlled and are used to:

- Monitor material movements into and out of the stores
- Check stock levels and rotations
- Check the use of materials in the process
- Check the destinations for delivery of products.

Daily cleaning routines are used as part of a plan to prevent dust or spilt food from accumulating which would encourage insects or rodents. Large warehouses use computerized truck-routing systems, which store information on stock levels, their location in a warehouse and warehouse layout. Computers that control automated guided vehicles (AGVs) have been used for several years. The AGVs follow fixed routes guided either by wires buried in the warehouse floor or coloured lines painted onto the floor. These are now being replaced by 'free-path AGVs in which the computer assigns an optimum route for each vehicle. Packaged goods are palletised and each pack and pallet is coded with a bar code that is read by a microprocessor. The coded stock is allocated a storage location by the computer, which compiles both a map of the warehouse and current stock levels in its memory. The progress of each AGV in retrieving or replacing stock is monitored and controlled using the information transmitted by an odometer in the vehicle and by bar-code directions that are displayed throughout the warehouse, which are read by a laser mounted on the truck.

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

Some of the basic factors to be taken into consideration in warehouse design and construction are as follows:

1. The site where the building is located must be well-drained and not subject to flooding. A swampy location will not only encourage the penetration of ground moisture into the stored

produce but the soil bearing capacity would be reduced as the moisture content increases and there is a tendency towards failure.

2. The floor in addition should be made moisture-proof by incorporating a moisture barrier in the foundation layer before putting the final concrete.
3. The wall should be plastered smooth and devoid of any crack where insects may hibernate or hide.
4. The doors and windows should be tight fitting to provide partially air-tight conditions for fumigation purposes which may be required from time to time. Such tight-fitting conditions will also help to control the entry of rodents.
5. The roof should be leak-proof to prevent the entry of rainwater into the store.
6. The eaves should be completely sealed such that they do not provide an avenue for entry by birds and rodents.

3.3.2 Space Requirement of a warehouse

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

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

3.3.3 Off-Season Checking of Storage Equipment

The following checklist is very important, as adhering to it will help to identify and solve problems of storage equipment:

a) Thoroughly clean all equipment with a high-pressure washer.
b) Lubricate all points.
c) Coat all parts that rust easily, such as ploughshares or chrome hydraulic cylinder rods, with a high-quality protectant.
d) Inspect all equipment for broken, bent or worn parts. Repair or replace as necessary.
e) Apply touch-up paint to scratched or rusted areas.

f) Apply a generous coating of wax to help the equipment fight the effects of the elements.
g) Store equipment in a shed or under a tarp or heavy plastic if possible.

SELF-ASSESSMENT EXERCISE

T	**F**	The roof of a warehouse does not need to be leakproof
T	**F**	A generous coating of wax needs to be applied to equipment during the off-season
T	**F**	Packaging of food does not enhance the protection and convenience of handling
T	**F**	Warehouse management systems are increasingly computer-controlled and are used to monitor material movements into and out of the stores
T	**F**	The site where a warehouse is located must be well-drained and not subject to flooding

4.0 CONCLUSION

When equipment is checked carefully and regularly, small problems can be identified and corrected before they cause downtime. Proper off-season checks will add value to farm equipment, increase its lifespan and decrease operating costs.

5.0 SUMMARY

This unit creates an understanding of the main causes of spoilage of stored foods and ingredients. It helps you to appreciate why warehouses should be encouraged to be computerized, and outlines key points that can be used as a checklist to identify and solve problems of storage equipment:

6.0 TUTOR MARKED ASSIGNMENT (TMA)

1. What are the main causes of spoilage of stored foods and ingredients?
2. What are the reasons for food packaging?
3. Why should warehouses be encouraged to be computerized?
4. Outline five (5) points that could be used as a checklist to identify and solve problems of storage equipment:

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