NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: CPT514

COURSE TITLE: PRODUCE /POST HARVEST MANAGEMENT

CPT514: PRODUCE /POST HARVEST MANAGEMENT

COURSE GUIDE

TABLE OF CONTENTS

Introduction

Produce/ post harvest management is a two credit course for 500L students of BSC. (Agricultural Extension & Management). The course consists of 3 modules in 12 units which deal with the basic principles and practice of post harvest management. 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 in order to complete it successfully. It also gives you some guidance on your tutor marked assignments.

What you will learn in this course

The main aim of this course "Produce/post harvest management" is to introduce the fundamental principles upon which post harvest management practices are based. By studying the produce post harvest management you would be able to understand the physiological processes of maturity, pre-harvest, post harvest losses, how to minimize these losses and ensure quality produce up to the consumer. So that you would be able to manipulate the plants and their external conditions for better handling, storage, increased shelf life and processing of agricultural produce

Course Aims

The aim of the cause is to acquaint you with the basic information on post harvest physiology, post harvest losses and their causes and measures to reduce them. Self life extension, processing, transportation and storage

This would be achieved through:

- Introducing you to the basic concepts of crop post harvest physiology
- Creating a better understanding of plants, the storage environment, post harvest losses their causes and measures to minimize them
- Developing a clear understanding of the role of the surrounding condition of the plant in minimizing post harvest losses, increasing self life, processing and storage of produce
- Introduce you to the various cultural practices upon which is laid successful post harvest management of farm produce
- Identification of storage pest, and diseases so that you can select appropriate method of control
- Identifying the best practices of harvesting, minimizing losses, increasing shelf life, transportation, processing and storage of field crop

In order to achieve the set aims, certain overall objectives have been set. In each unit specific objectives are set. These are usually included at the beginning of the unit. You should pay attention to the objectives of each unit before starting to go through them. You can always refer back to the unit's objectives to check your progress. You should also look at them after completing a unit. By so doing you can be sure that you have achieved what the unit expects you to acquire.

Course Objectives

Below are the wider objectives of the whole course. By meeting these objectives, the aims of the course as whole would have been achieved.

- Give classification of maturity and maturity index of most horticultural crops
- Understand the post harvest management and the technical and managerial resources that are utilized in the process of produce harvest, processing and storage
- Identify the most appropriate post harvest technology to apply in processing, extension of shelf life and storage of produce
- Describe the various post harvest practices for minimizing losses, extension of shelf life and storage
- Identify the most critical periods in post harvest life of plant in relation to storage and recommend technologies that are most appropriate.
- Describe methods of processing produce
- Identify the common pest of crop in storage and describe the control measures to effectively tackle the problems of rodents and pest of storage

Working through this course

To complete this course you are required to read the study units, read 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 which you are expected to submit for marking the TMA forms part of continuous assessments.

At the end of the course 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 in order to complete the course successfully on time.

Course Materials

The main components of the course are:

1. course guide
2. study units
3. references
4. tutor marked assignments

Study units in this course are as follows

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

Unit1. Climatic factors (rainfall, temperature, relative humidity sunshine etc.) in Relation to Maturity, Ripening and Senescence

Unit2. Soil factors (plant nutrients, soil reaction pH) in Relation to Maturity Ripening and senescence

Unit3. Maturity Indices of Crops Products

Module 2: Post Harvest Handling of Crops

Unit 1: Introduction to Post Harvest Technology

Unit 2: Causes of Post Harvest Losses

Unit 3: Post Harvest Treatments to Minimize Produce Contamination and Maximize Quality

Unit 4: Crop Processing

Module 3: Storage of Crop Products

Unit 1: Storage life of Harvested Crop Materials

Unit 2: Storage and Shelf life problem

Unit3: Methods of Crop Storage

Unit 4: Ideal Environment for Storage

Unit 5: Operational/Structures for Storage and Preservation

Tutor Marked Assignments (TMA)

There are 3-4 tutor marked assignments in each unit. You would have to do the TMA as a revision of each unit. This would help you to have broad view and better understanding of the subject.

Your tutorial facilitator would inform you 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 contain in this course material and references; however, it is desirable to research more other references, which will give you a broader view point and a deeper understanding of the subject.

Final Examination and Grading

The final examination for the course will be 2hrs duration and consist of section A which contains 50 objectives questions which you are expected to answer all and section B which is fill in the blank spaces questions you are to answer all the question in this section too. The total mark for the final examinations is 70 marks that is 30 marks from TMA. The examination will consist of questions, which reflect the tutor marked assignment which you have previously encountered. All areas of the course will be covered by the assessment.

Use the time between finishing the last unit and sitting the examination to revise the entire course. You might find it useful to review your tutor marked assignments before the examination. The final examination covers information from all parts of the course.

Table.1

Assessment	Marks
Tutor marked assignment 1-4	10 marks each, the best three would recorded to give you 30%
Final examination	70%
Total	100% of course marking scheme

Course Overview

This table brings together the units, number of weeks you should take to complete them and the assignment that follows them.

Table.2 Course organizer

Unit	Title of work	Period of activity	TMA at the end of the unit
	Course guide	1	
1	**Module 1: Tropical Environment in Relation to Maturity, Ripening and Senescence** I. Unit1. Climatic factors (rainfall, temperature, relative humidity sunshine etc.) in Relation to Maturity, Ripening and Senescence Unit2. Soil factors (plant nutrients, soil reaction pH) in Relation to Maturity Ripening and senescence Unit3. Maturity Indices of Crops Products	4	8

2	**Module 2: Post Harvest Handling of Crops** Unit 1: Introduction to Post Harvest Technology Unit 2: Causes of Post Harvest Losses Unit 3: Post Harvest Treatments to Minimize Produce Contamination and Maximize Quality Unit 4: Crop Processing	4	16
4	**Module 3: Storage of Crop Products** Unit 1: Storage life of Harvested Crop Materials Unit 2: Storage and Shelf life problem Unit3: Methods of Crop Storage Unit 4: Ideal Environment for Storage Unit 5: Operational/Structures for Storage and Preservation	5	20
	Revision	2	
	Total	16	44

How to get the most from this course

In distance learning the study units replace the university lectures. This is one of the great advantages of distance learning; you can read and work through specially designed study materials at your own pace, and at a time and place that suit you best. Think of it as reading the lecture instead of listening to the lecturer. In the same way that a lecturer might set you some reading to do, the study units tell you when to read your set books or other materials. Just as a lecturer might give you an in-class exercise, your study units provide exercise for you at appropriate points.

Each of the study units follows a common format. The first item is introduction to the subject matter of the unit and how a particular unit is integrated with the other units and the course as a whole. Next is a set of learning objectives. These objectives let you know what you should be able to do by the time you have completed the unit. You should use these objectives to guide your study. When you have finished the unit you must go back and check whether you have achieved the objectives or not. If you make a habit of doing this you will significantly improve your chances of passing the course.

The main body of the unit guides you through the required reading from other sources. This will usually be either from your set books or the reading list

When you need help, don't hesitate to call and ask your tutor to provide it.

1. Read the course guide thoroughly.
2. Organise a study schedule. Refer to the "Course Overview" for more details. Note the time you are expected to spend on each unit and how the assignments relate to the units. Important information details of your tutorials and the date of the first day of the semester is available at the National Open University of Nigeria, Study Centre. You need to gather all these information in one place, such as your diary or wall calendar. Whatever method choose to use, you should decide on and write in your own dates for working on each unit.
3. Once you have created your own study schedule, do everything you can to stick to it. The major reason that students fail is that they get behind with their course work. If you get into difficulties with your schedule, please let your tutor know before it is too late.
4. Turn to unit 1 and read the introduction and the objectives for the unit.
5. Assemble the study materials. Information about what you need for a unit is given in the introduction and objectives of the course at the beginning of each unit.
6. Work through the unit, the content of the unit itself has been arranged to provide a sequence for you to follow.

7. Keep in mind that you will learn a lot by doing the assignments carefully. They have been designed to help you meet the objectives of the course and, therefore will help pass the exams.
8. Review the objectives for each unit to confirm that you have achieved them. If you feel unsure about any of the objectives, review the study material or consult your tutor.
9. When you are confident that you have achieved a unit's objectives, you can then start on the next unit. Proceed from unit to unit through the course and try to pace your study so that you keep yourself on schedule.
10. When you have submitted an assignment to your tutor for marking, do not wait for its return before starting on the next. Keep to your schedule. When your assignments returned, pay particular attention to your tutor's comments. Consult your tutor as soon as possible if you have any question or problems.
11. After completing the last unit, review the course and prepare yourself for the final examination. Check that you have achieved the unit objectives and the course objectives listed in the course guide.

Summary

This course intends to introduce you to the principle of produce post harvest management. Upon completion of this course you would be equipped with basic knowledge and understanding of the various areas that make up post harvest management. After successfully going through this course you would be able to answer the following questions:

- Define post harvest technology
- Describe post harvest physiological process
- Describe procedures of controlling relative humidity and temperatures during storage
- Explain the pre-harvest factors that affect post harvest life of produce
- Distinguish the different types of crop maturity
- Describe the different stages of crop maturity
- Describe the following crop maturity indices i.e. colour, size, firmness, sugar content, acidity and aroma.
- Describe the causes of post harvest losses
- Explain the sites of losses

- Explain the causes of damage in the marketing chain
- Describe climatic factors that causes loss of produce
- Describe how can post harvest losses be prevented
- Describe post harvest treatment to minimize loss and maximize quality of produce
- Discuss the principles of food safety
- Describe the treatments that can be applied to minimize water loss in fruits and vegetables
- Describe the treatments for controlling decay
- Describe the basic principles which must be applied correctly for successful refrigeration of perishable
- Explain the role of pest and diseases in causing crop loss and measures to control them
- Explain suberization and curing
- Define shelf life extension
- Describe shelf life extension by canning, drying and freezing
- Describe the various degrees of preservation by heating
- Describe factors which determine influence the action of chemical food preservation
- Explain the phenomena that influence the drying process
- Describe the recent developments in post-harvest technology of fresh fruits and vegetables
- Describe blenching as a method of food preservation
- Enumerate the requirements of modern packages for fresh fruits and vegetables
- Explain the procedures to make packages more effective
- Describe controlled atmosphere package
- Describe vacuum and edible packaging
- Describe methods of storage that does not require refrigeration
- Describe methods of regulating conditions in storage rooms
- Describe controlled atmosphere storage
- Correctly store crop products

You should be able to use the knowledge acquired in this course in planning and executing successfully post harvest storage and management of crop produce. I wish you success in this course and hope that you find it both interesting and useful.

CPT 514: PRODUCE/POST HARVEST MANAGEMENT

COURSE DEVELOPER/WRITER: **Dr. Jari Sanusi**
School of Science and Technology
National Open University of Nigeria
Lagos

COURSE EDITOR: **Dr. Enejo Attah**
Department of Crop Production
Kogi State University, Anyigba

PROGRAMME LEADER : **Dr. N. E. Mundi**
School of Science and Technology
National Open University of Nigeria
Lagos

COURSE COORDINATOR: **Mr. Samuel Awolumate**
School of Science and Technology
National Open University of Nigeria
Lagos

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

UNIT1: CLIMATIC FACTORS IN RELATION TO CROP MATURITY, RIPENING AND SENESCENCE

TABLE OF CONTENTS

UNIT2: SOIL FACTORS IN RELATION TO CROP MATURITY, RIPENING AND SENESCENCE

Table of contents

UNIT3: MATURITY INDICES OF CROP PRODUCTS

Table of Contents

UNIT 1: INTRODUCTION TO POST HARVEST TECHNOLOGY

UNIT 2: CAUSES OF POST HARVEST LOSSES

UNIT 3 TECHNOLOGIES OF REDUCING POST HARVEST LOSSES

UNIT 4 POST-HARVEST TREATMENTS TO MINIMIZE PRODUCE CONTAMINATION AND TO MAXIMIZE QUALITY

UNIT 5 CROP PRODUCT PROCESSING

UNIT 1: INTRODUCTION TO POST HARVEST TECHNOLOGY

Table of Contents

Table of Contents

UNIT 3 TECHNOLOGIES OF REDUCING POST HARVEST LOSSES 73

Table of Contents

UNIT 4 POST-HARVEST TREATMENTS TO MINIMIZE PRODUCE CONTAMINATION AND TO MAXIMIZE QUALITY 88

Table of Contents

Table of contents

Table of contents

Table of contents

Table of contents

Table of Contents

UNIT 5: OPERATIONAL EQUIPMENTS/STRUCTURES OF STORAGE AND PRESERVATION 238

Table of contents

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

UNIT1: CLIMATIC FACTORS IN RELATION TO CROP MATURITY, RIPENING AND SENESCENCE

UNIT2: SOIL FACTORS IN RELATION TO CROP MATURITY, RIPENING AND SENESCENCE

UNIT3: MATURITY INDICES OF CROP PRODUCTS

UNIT1: CLIMATIC FACTORS IN RELATION TO CROP MATURITY, RIPENING AND SENESCENCE

TABLE OF CONTENTS

1.0 Introduction

The **climatic factors** include rainfall and water, 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 post harvest quality of crop produce.

2.0 Objectives

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

- Describe elements of climate that effect plant growth and development
- Describe the effect of temperature on plant growth and development
- Explain the effects of sunshine on crop growth and development
- Explain the effects of relative humidity on crop growth and development
- Describe the effect of rainfall on crop growth and development
- Describe how air and wind effect crop growth and development
- Able to plan adequately for production of crop bearing in mind the climatic elements that affect plant growth and development
- Carry out harvesting of fruits and vegetable at the most optimal time for maximum quality and profitability

3.0 Climatic factors in relation to maturity, ripening and senescence of crop

The **climatic factors** include *rainfall* and *water*, *light*, *temperature*, *relative humidity*, *air*, and *wind*. They are abiotic components, including *topography* and *soil*, of the environmental factors that influence plant growth and development.

3.1 Rainfall and Water

Rainfall is the most common form of **precipitation**. It is the falling of water in droplets on the surface of the Earth from clouds. Other forms of precipitation are *freezing rain*, *sleet or ice pellets*, *snowfall*, and *hail*. 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 fresh weight basis, although only a small fraction of the water absorbed is utilized. Most of the water absorbed is lost through *transpiration* and only about 1 percent or less is used in the various biochemical processes

This climatic factor is essential to all plants and living organisms. Anaerobic organisms can live without oxygen, but they cannot without water. Some plants called *xerophytes*, however, are more tolerant to scarce water while others, called *hydrophytes*, are adapted to watery or water-logged habitats

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 vapor.

However, as with other climatic factors, excess water within the plant can produce unfavorable effects on growth and development. Under conditions that favor high absorption and low transpiration rates, there is build-up of high turgor pressure in the region of cell elongation which causes maximum swelling of the cells. This results to the development of *leggy seedlings*. Likewise, under similar conditions, *growth cracks* occur as exemplified by bursting heads of cabbage and cracked fruits of tomato and roots of carrot and sweet potato

The possibility that certain climatic factors can cause deleterious effects is further exemplified by the acid rain. With dissolved sulfuric acid and nitric acid that are formed in the air from sulfur dioxide and nitric oxide generated by power plants, smelters, other industrial plants, factories and cars, acid rain can cause serious injury to plants

Pre-harvest sprouting in wheat is triggered by rainfall, amount of rain, duration of the rain event and weather conditions after the rain (i.e. do they favour the grain remaining wet or do they favour drying).As a rule of thumb, around 10-15 mm of rain is probably the minimum required to initiate sprouting but obviously if it is spread over several hours it is likely to have more effect than if it all falls in 1 hour. Overall, for crops at harvest-ripeness, the grain will need to stay moist for around 2 days although this time will decrease the longer harvest is delayed.

A deficiency or excess of water may influence 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 con- tent and provides more favorable conditions for mechanical fruit injury and rot. If straw- berry plants are overirrigated, especially at harvest, the fruit is softer and more susceptible to bruising and decay.

Heavy rainfall leads to water logging and affects adversely the flowers and fruits.

At blossoming, rain washes away stigmatic fluid & pollen from stigma.

Rain before harvesting cause softening of fruits in banana &

Date palm and induce infection of fruit fly in guava & peach.

Water deficits have been shown to delay development of fl oral primordial 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.

3.2 Temperature

The degree of hotness or coldness of a substance is called **temperature**. It is commonly expressed in degree Celsius or centigrade (C) and degree Fahrenheit (F). This climatic factor 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 photosynthate is faster so that plants tend to mature earlier.

In general, plants survive within a temperature range of 0 to 50^{o}C. Enzyme activity and the rate of most chemical reactions generally increase with rise in temperature. Up to a certain point, there is doubling of enzymatic reaction with every 10^{o}C 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 viscuous at low temperatures and less mobile, and the protoplasm is less permeable. At temperatures below the freezing point of water, there is 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 favorable or optimal day and night temperature range for plant growth and maximum yields varies among crop species. According to McKinley (2005), orchid plants are generally grouped into the following three temperature categories: *cool*, *intermediate* and *warm*. Orchids need a day-night temperature difference of 10-15 F or about 5.55-8.34 C to flower. The exact temperature ranges that are associated with these terms vary, the following ranges being more common:

Cool: 60-70 F or 15.55-21.11 C (day), 50-55 F or 10-12.77 C (night); **intermediate**: 70-80 F or 21.11-26.66 C (day), 55-65 F or 12.77-18.33 C (night); and **warm**: 80-90 F or 26.66-32.22 C (day), 65-70 F or 18.33-21.11 C (night).

The growth of most crops ceases below a critical low temperature and very high temperatures (usually above 30 – 35^{o}C) have adverse effects.

Crops are divided into five adaptability groups on the basis of 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 potential for growth 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.

Table 1.1.1 PHOTOSYNTHETIC PATHWAYS AND RESPONSE TO RADIATION AND TEMPERATURE

Photosynthetic pathway	**C3**	**C3**	**C4**	**C4**	**CAM**
Optimum	15-20	25-30	30-35	20-30	25-35

temperature for photosynthesis ^oC					
Examples of crops	Sugarbeet Phaseolus Wheat Barley Oats Potato Bean (TE) Chickpea	Soybean (TR) Phaseolus Rice Cassava Sweet Potato Yams Bean (TR) Groundnut Cotton Tobacco Banana Coconut Rubber Oil palm	Sorghum (TR) Maize (TR) Pearl millet Panicum Millet (TR) Finger millet Setaria Sugarcane	Panicum Millet (TE, TH) Sorghum (TE, TH) Maize (TE, TH) Setaria	Sisal Pineapple

TE = Temperate cultivars; TR = Tropical (lowland) cultivars; TH = Tropical (highland) cultivars.

Source: Based on information extracted from FAO 1978a and FAO 1980c.

The growing cycle is the period required for an annual crop to complete its annual cycle of establishment, growth and production of harvested part. Perennial crops have growing cycles of more than one year.

The growing period for annual crops is the duration of the year when temperature, soil. water supply and other factors permit crop growth and development.

Thus, a growing cycle is a property of the crop (i.e. a crop requirement) whereas a growing period is a condition of the land (i.e. a land quality or land characteristic).

The growing period is a major determinant of land suitability for crops and cultivars on a worldwide and continental scale

In subtropical and temperate climates, there are winter and summer growing periods due to seasonal temperature changes.

Growing periods can be constrained by wet or humid conditions that limit opportunities for ripening and drying the crop, or which lead to problems of quality (e.g. reduced sugar content of sugarcane, staining of cotton, blemishes on fruits, etc.).

Temperature – the effects of temperature on sprouting are quite complex and still not completely understood. However, provided the crop is not under moisture stress then warmer temperatures during ripening tend to result in greater susceptibility to sprouting at harvest-ripeness. If the crop is under moisture stress combined with high temperatures then susceptibility to sprouting is significantly reduced.
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 prior to 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 prior to harvest were found to influence the acid and sugar content of Pears. Increased acid and sugar levels were reported in pears produced at 17.2^{o}C and 13.9^{o}C DHA temperatures, whereas in pears grown at 20.0^{o}C and 11.7^{o}C, the ripening capacity was low.

3.3 Relative Humidity

The amount of water vapor that the air can hold depends on its temperature; warm air has the capacity to hold more water vapor than cold air. There is almost one-half reduction in the amount of water vapor that the air can hold for every 10 C drop in temperature.

Relative humidity (RH) is the amount of water vapor in the air, expressed as the proportion (in percent) of the maximum amount of water vapor it can hold at certain temperature. For example, an air having a relative humidity of 60% at 27^{o}C temperature means that every kilogram of the air contains 60% of the maximum amount of water that it can hold at that temperature

The amount of water vapor in the air ranges from 0.01% by volume at the frigid poles to 5% in the humid tropics. Compared to dry air, moist air has a higher relative humidity with relatively large amounts of water vapor per unit volume of air.

The relative humidity affects the opening and closing of the stomata which regulates loss of water from the plant through transpiration as well as photosynthesis. A substantial understanding of this climatic factor is likewise important in plant propagation. Newly collected plant cuttings and bareroot seedlings are protected against dessication by enclosing them in a sealed plastic bag. The *propagation chamber* and *plastic tent* are also commonly used in propagating stem and leaf cuttings to ensure a condition with high relative humidity.

3.4 Sunshine

Light is a climatic factor that is essential in the production of chlorophyll and in **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*

Light is that visible portion of the **solar radiation** or **electromagnetic spectrum**. It is a form of kinetic energy that comes from the sun in tiny particles called *quanta* or *photons*, travelling in waves.

Three properties of this climatic factor 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; and **day length** is the duration of the day with respect to 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.

Radiation 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 is 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 winter months. Sunshine influence 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 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) with respect to their transformation from vegetative to reproductive growth

Short-day plants are induced to flower with a lengthening of the dark period. This was one of the first photoperiodic responses identified and extensively studied. Long-day plants react in the opposite, being induced to flower with the shortening of the dark period while day-neutral species appear to be unaffected by changes in photoperiod with respect to entering their reproductive phases. In broad general terms, plants that evolved in tropical environments are SDP with no vernalization (exposure to cold temperature) requirement while plants that evolved in the higher latitudes are LDP, often with a vernalization requirement. Day-neutral plants ca

3.5 Wind

Air movement or **wind** is due to the existence of pressure gradient on a global or local scale caused by differences in heating. On a global scale it consists of the jet stream flow and movement of large air masses. On the local scale only a smaller quantity of air moves. Surface winds are lower and less turbulent at night due to the absence of solar heating

When air that is close to the ground cools, it contracts and the pressure rises; when it warms, it expands and loses pressure. Where both cold and warm air occur in proximity, as over a lake and its adjacent shore, the cold flows to the direction of the warm air or from high to low pressure area to correct the pressure imbalance. This also happens in tropical Asia but in a larger and more complex way, as the *monsoon* winds

This climatic factor 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 grasses.

Moderate winds favor 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

Each of the above discussed climatic factors has been shown to produce limiting effects on various growth processes. However, the various climatic factors always operate together and interact with each other under natural conditions.

High velocity and hot winds cause shedding of flowers and dropping of immature fruits and retard activity of pollinators.
Bee activity is maximum when wind is still, little reduced when wind is 2-3 km/hr, greatly reduced at 25 km/hr, activity ceased at 45km/hrs

3.6 Air

The **air** is a mixture of gases in the atmosphere. About 75% of this 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 are 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 (CH_4), propane, chlorofluorocarbons (CFCs), solid particles of dust, soot, asbestos and lead, ozone and many more.

However, the composition of this climatic factor is susceptible of variation. Recently, there has been a heightened alarm about the increase of carbon dioxide in the atmosphere 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.

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

These climatic factors (rainfall, temperature, relative humidity, sunshine, wind and air) influences all plant growth processes such as photosynthesis, respiration, transpiration, breaking of seed dormancy, seed germination, protein synthesis, and translocation

Three properties of sunshine that affect plant growth and development are light quality, light intensity, and day length or photoperiod.

The oxygen and carbon dioxide in the air are 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. A deficiency or excess of the climatic factors may influence growth and development of crop and postharvest quality

6.0 Tutor Marked Assignment TMA

i. Describe the effect of rainfall on growth and development of crops
ii. Describe how temperature affect the growth and development of crops
iii. Explain how relative humidity influences the growth and development of crops
iv. Enumerate the effects of sunshine on crop growth and development
v. Give examples of effects of elements of climatic on crop maturity and ripening

7.0 References and Further Readings

1. A.A. Kader (ed) (2002) Postharvest Technology of Horticultural Crops, third edition. University of California, ANR Publication 3311.
2. Bapat, V. A.,Trivedi, P. K., Gosh. A. and Sane. V. A 2010. Ripening of fleshy fruits: molecular insight and the role of ethylene. Biotechnol. Adv. 28:94-107
3. Bautista, O.K. and Mabesa, R.C. (eds). 1977. Vegetable Production. University of the Philippines at Los Banos.
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
6. Kader, A. A. 1983. Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
7. Kader A. A. 1999. Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
8. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469
9. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
10. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257, in:
11. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California, Division of Agriculture and Natural Resources, UC Bulletin 1914.
12. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266

13. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
14. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
15. http://www.postharvest.ucdavis.edu
16. http://www.fao.org/docrep
17. http://www.crcpress.com/product
18. http://www.actahort.org/books
19. http://sciencedirect.com/science/journal
20. http://www.stewartspostharvest.com

UNIT2: SOIL FACTORS IN RELATION TO CROP MATURITY, RIPENING AND SENESCENCE

8.0 Introduction

9.0 Objectives

10.0 Soil factors in relation to crop maturity, ripening and senescence

3.1.4. Soil acidity

3.1.5. Soil texture

3.1.6. Soil moisture

3.3 Mineral nutrition

3.3.1 Nitrogen

3.3.2 Phosphorous

3.3.3 Potassium

3.3.4 Calcium

11.0 Conclusion

12.0 Summary

13.0 Tutor Marked Assignment (TMA)

14.0 References and Further Readings

1.0 Introduction

Maintaining good, long-term soil fertility level and quality produce remains a primary goal of crop production. Achieving this goal will ultimately benefit the postharvest quality of vegetables grown on the farm, as the availability of the optimal levels of plant nutrients throughout the growing season will allow for optimal quality of the vegetables throughout the packing and distribution processes. Deficiencies or overabundances of certain plant nutrients can affect positively or negatively a crop's susceptibility to physiological disorders, disease, and negative composition and textural changes. Deficiencies or excess or imbalance of various nutrients are known to result in disorders that can limit the storage life of many fruit and vegetables. Several soil factors can directly or indirectly affect the growth and development of crop, maturation and nutritional quality of crops. Among these are soil factors, such as pH, available nutrients, texture, organic matter content and soil-water relationships.

2.0 Objectives

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

- Explain the role of soil factors in crop ripening and maturity
- Describe the role of nitrogen in the process of crop ripening and maturation
- Enumerate the nutritional disorders associated with nitrogen deficiency
- Discuss the role of calcium in crop nutrition
- Adequately plan the production of fruits and vegetable taking into the account the role of soil factor and nutrition in crop production

3.1 Soil factor in relation to crop maturity, ripening and senescence

Several soil factors can directly or indirectly affect the growth and development of crop, maturation and nutritional quality of crops. Among these are soil factors, such as pH, available nutrients, texture, organic matter content and soil-water relationships.
Soil is the medium on which crops grow and maintain their existence – in other words, soil forms the home of crops. Since soil varies in its composition – component constituents, its nature and reactions, the crops that do well in the different types of the soil also vary.

3.1.1 Soil acidity

Soil acidity is the measure of hydroxyl ion concentration in the soil. When the concentration of hydrogen ions is higher than the hydroxyl ions, the soil is said to be acidic. When the concentrations of both the hydroxyl and hydrogen are the same, the soil is said to be neutral. When the soil is acidic, some elements are easily released to the crops while some are tied up. A reversed condition occurs if the soil is alkaline. When the soil pH is 7, the soil is said to be neutral. When the soil pH is less than 7, the soil is said to be acidic when the pH is higher than 7, the soil is said to be alkaline. Crop nutrition is optimal when the soil pH is neutral

3.1.2 Soil Texture

Soil texture is the relative relations of the components sand, silt and clay most often reported as percentages on a mass basis. The texture of the soil on which certain vegetable crops are grown may also affect the postharvest quality. For example, carrots grown on muck soils have been shown to have a greater concentration of terpenoids, a chemical that imparts a bitter flavor, than carrots grown on sandy soil.

3.1.3 Soil moisture

Adequate soil moisture during the pre-harvest period is essential for the maintenance of postharvest 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 flavor 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.

3.2. Mineral nutrition

Nutritional status is an important factor in quality at harvest and postharvest life of various fruits and vegetables. Deficiencies, excesses, or imbalances of various nutrients are known to result in delayed or ultra early maturity and related disorders that can limit the storage life of many fruits and vegetables. Fertilizer application rates vary widely among growers and generally depend upon soil type, cropping history; and soil test results, which help indicate nitrogen (N), phosphorous (P), and potassium (K) requirements. To date, fertilization recommendations for fruits and vegetables have been established primarily for productivity goals, not as diagnostics for good flavor quality and optimal postharvest life. Lack of nutrients in the soil can seriously affect the fresh produce at harvest.

3.2.1Nitrogen:

The nutrient with the single greatest effect on fruit maturity and quality is nitrogen.

Nitrogen, as a key component of plant proteins, plays an important role in plant growth and development. Because of nitrogen's involvement in protein synthesis, soil nitrogen deficiencies may lead to lower protein concentrations in vegetables, thereby affecting the nutritional composition of the crop. Adequate soil nitrogen supplies allow for the optimal development of vegetable color, flavor, texture, and nutritional quality.

Response of peach and nectarine trees to nitrogen fertilization is dramatic. High nitrogen levels stimulate vigorous vegetative growth, causing shading and death of lower fruiting wood. Although high-nitrogen trees may look healthy and lush, excess nitrogen does not increase fruit size, production, or soluble solids content (SSC). Furthermore, excessive nitrogen delays stone fruit maturity, induces poor red colour development, and inhibits ground colour change from green to yellow. However, nitrogen deficiency leads to small fruit with poor flavor and unproductive trees.

In vegetable crops, excessive nitrogen levels induce delayed maturity and increase several disorders that diminish postharvest quality. Disorders such as grey wall or internal browning in tomato, hollow stem of broccoli, lower soluble solids concentration in potato, fruit spot in peppers, and growth cracks and hollow heart in broccoli and cauliflower have been associated with high nitrogen. High nitrogen has also been associated with increased weight loss during storage of sweet potatoes and soft rot in tomatoes. Excessive soil nitrogen can negatively impact vegetable quality in several ways. High nitrogen can result in composition changes such as reduced ascorbic acid (vitamin C) content, lower sugar content, lower acidity, and altered ratios of essential amino acids. In leafy green vegetables grown under low light, it can result in the accumulation of nitrates in plant tissues to unhealthy levels. High nitrogen fertilization can lead to reduced volatile production and changes in the characteristic flavor of celery.

Research has shown that too much soil nitrogen can reduce the vitamin C content of Green leafy vegetables such as swiss chard. Excess nitrogen may lower fruit sugar content and acidity. In certain situations, leafy green plants may accumulate excess soil nitrogen, leading to high concentrations of nitrates in the harvested greens.

Specific examples of excess nitrogen negatively affecting crop quality include

- Altered celery flavor
- “Brown-checking” of celery
- Weight loss of sweet potato during storage
- Hollow stem in broccoli
- Soft rot in stored tomatoes

3.2.2Phosphorus

Phosphorus and potassium also play very important roles in plant growth and development. Phosphorus is a key component of DNA and plant cell membranes. This element also plays a key role in plant metabolic processes. High levels of soil phosphorus have been shown to increase sugar concentrations of fruits and vegetables while decreasing acidity.

3.2.3Potassium:

Potassium is important in plant water balance and enzyme activation. High levels of soil potassium often have a positive effect on the quality of vegetables. Increased soil potassium concentrations have been shown to increase the vitamin C and titratable acidity concentrations of vegetables and improve vegetable color. Potassium also decreases blotchy ripening of tomato.

3.2.4 Calcium:

Element calcium is important to plant cell walls and membranes. Deficiencies in soil calcium have been associated with a number of postharvest disorders, including blossom end rot of tomato, pepper, and watermelon; brown heart of escarole; blackheart in celery; and tipburn of lettuce, cauliflower and cabbage that reduce the quality and marketability of these commodities. High soil calcium concentrations reduce these disorders and are associated with other postharvest benefits, including increased vitamin C content, extended storage life, delayed ripening, increased firmness, and reduced respiration and ethylene production

Although calcium (Ca) is classified as a secondary nutrient, it is involved in numerous biochemical and morphological processes in plants and has been implicated in many disorders of considerable economic importance to the production and postharvest quality of fruits and vegetables. Certain calcium deficiency disorders, such as bitter pit in apples and blossom end rot in tomatoes, may be lessened through proper irrigation, fertilizer management, and supplemental fertilization. However, for tip bum of lettuce, a physiological disorder caused by the lack of mobility of calcium in the heads during warm weather and rapid growing conditions, there is currently no pre-harvest control practice.
Ca is often considered to be the most important mineral dement in determining fruit quality, especially in apples and pears where it has been demonstrated to reduce metabolic disorders, maintain firmness and reduce decay.

4.0 Conclusion

Soil is the medium on which crops grow and maintain their existence. Several soil factors can directly or indirectly affect the growth and development of crop, maturation and nutritional quality of crops. Among these are soil factors, such as pH, available nutrients, texture, organic matter content and soil-water relationships.

Deficiencies, excesses, or imbalances of various nutrients are known to result in delayed or ultra early maturity and related disorders that can limit the storage life of many fruits and vegetables.

5.0 Summary

Soils as a medium for the growth and development of fruits and vegetable have direct relation to the growth, development and quality of crop product. Soil factors such as soil texture, soil moisture, soil reactions and soil mineral nutrients have direct influence on growth and development of crops. The quality and post harvest shelf life of some fruits and vegetable are directly related to the soil factors of production.

6.0 Tutor Marked Assignment (TMA)

i. Enumerate the effect of excess nitrogen application on crops
ii. Enumerate the nitrogen deficiency disorder on crops
iii. Describe the role of calcium in crop nutrition and development
iv. Enumerate disorders associated with Ca deficiency
v. Explain the essential role of soil moisture in physiological processes of growth and development of crop.

7.0References and Further Readings

1. A.A. Kader (ed) (2002) Postharvest Technology of Horticultural Crops, third edition. University of California, ANR Publication 3311.
2. Bapat, V. A.,Trivedi, P. K., Gosh. A. and Sane. V. A 2010. Ripening of fleshy fruits: molecular insight and the role of ethylene. Biotechnol. Adv. 28:94-107
3. Bautista, O.K. and Mabesa, R.C. (eds). 1977. Vegetable Production. University of the Philippines at Los Banos.
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
6. Kader, A. A. 1983. Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
7. Kader A. A. 1999. Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
8. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469
9. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
10. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257, in:

11. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California, Division of Agriculture and Natural Resources, UC Bulletin 1914.
12. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
13. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
14. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
15. http://www.postharvest.ucdavis.edu
16. http://www.fao.org/docrep
17. http://www.crcpress.com/product
18. http://www.actahort.org/books
19. http://sciencedirect.com/science/journal
20. http://www.stewartspostharvest.com

UNIT3: MATURITY INDICES OF CROP PRODUCTS

Table of Contents

3.2.2 Chemical method

3.2.3 Physiological method

3.2.4 Other methods

3.3 Maturity indices

3.3.1 Physical indices of crop maturity

3.3.2 Chemical indices of crop maturity

3.4 Maturity Standard

4.0 Conclusion

5.0 Summary

7.0 Tutor Marked Assignment (TMA)

7.0 References and Further Reading

1.0 Introduction

The time necessary for crops to successfully complete reproduction is species and environment dependent. Lifecycles can be completed in a few weeks or take several years depending on the plant species. Crop development is divided into phenophases that are affected primarily by light and temperature changes, interacting with phytohormones. Some species are influenced more by light and others by temperature. Maturity in virtually all crops can be divided into two types, **physiologica**l **maturity** which describes that period when sexually induced reproductive growth has ceased, and **harvest maturity**, where the seed, fruit, or other economically important organ of yield has reached a state of "ripeness" and can be removed from the parent plant for consumption. For most agronomic crops maturity ratings refer to the time from germination until physiological maturity. Days to harvest maturity can be different from one season to the next for the same cultivar and is greatly influenced by environmental conditions, especially temperature; relative humidity; and extent of cloud cover after physiological maturity.

2.0 Objectives

At the end of studying this unit you would able to:

- have a clear understanding of what constitute maturity and ripening in crops
- distinguish physiological maturity from harvest maturity
- distinguish the three stages in the life span of fruits and vegetables
- differentiate maturation and repining
- describe what senescence is
- describe the various maturity index for some fruits and vegetable

- Explain the importance of maturity indices and their impact on shelf-life and quality.
- Determine maturity stage of fruits and vegetables using subjective and objective maturity indices.

3.0 Maturity/ Quality indices of crop products

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

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 so as to allow them to withstand post-harvest handling conditions when shipped 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: (1) 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, strawberry, and tamarillo. Group 2 on the other hand, includes apple, apricot, avocado, banana, cherimoya, guava, kiwifruit, mango, nectarine, papaya, passion fruit, pear, peach, persimmon, plum, quince, sapodilla, and sapote.

Fruit of the Group 1 category, produce very small quantities of ethylene and do not respond to ethylene treatment except in terms of degreening (removal of chlorophyll); these should be picked when fully-ripe, if good flavor 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 prior to reaching full maturity. This often results in delayed harvest, and consequently in produce of low quality.

3.0 Quality indices of fruits

Quality i.e. the degree of excellence or superiority of fresh fruits and their products is combination of attributes, properties or characteristics that give each commodity value in terms of human food. The reletive 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 high yield and good appearance, must be easy to harvestand must withstand long distance shipping to markets. Appearance quality, firmness, and shelf-life are important from the point of view of wholesale and retail marketers. Consumers judge quality of fresh fruits on the basis of appearance including freshness and firmness at the time of initial purchases. subsequent purchases depend upon the consumers's 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, buut also a good source of energy, vitamins, minerals, dietery fibers and many bioactive compounds that enhance human health

Maturity indices are important for deciding when a given commodity should be harvested to provide some marketing flexibilty and ensure the attainment of acceptable eating quality to the consumer. These two goals are not always compatiable. The necessity of shiping fruits long distancehas 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 there are many important quality indices which are not used in determining optimum harvesting stage. The flavour quality of fruits cannot be accurately determined by 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)

3.1 Understanding Maturity, ripening and senescence

The principles dictating at which stage of maturity a fruit or vegetable should be harvested are crucial to its subsequent storage and marketable life and quality. Post-harvest physiologists distinguish 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.

3.1.1 Types of maturity

Physiological and commercial maturity

i. Physiological maturity – refers to a particular stage in the development of a plant or plant organ. A fruit is physiologically mature when its development is over. A physiologically mature fruit may not necessarily be commercially mature. For example, papayas are harvested for domestic markets at physiological maturity, i.e. when three-quarters of the fruit assumes a yellow-to-green colour.

ii. **Commercial maturity** – pertains to the timing of harvest to meet specific market and consumer requirements. A fruit is commercially mature when it reaches a developmental stage at which it can be marketed for a specific purpose, e.g. for consumption in the fresh state, or for processing. Papayas, for example, are harvested for export at the mature stage, i.e. when the fruit is firm and easy to handle. On arrival at the destination, the fruit is ripened in ripening rooms. Commercial maturity has little impact on physiological maturity.

3.1.2 Ripening

Ripening follows or overlaps maturation, rendering the produce edible, as indicated by taste. Ripening: The sequence of changes in texture, colour and flavour as a result of physiological and biochemical change that makes the fruit ready for consumption. Artificial ripening climacteric fruits are picked relatively green and subsequently ripened by introducing ethylene or acetylene gas (calcium carbide) e.g. Banana, Mango, Pear and Avocado.

On the basis of the respiratory pattern and ripening behavior fruits are carried into two classes *viz.*, climacteric fruits and non-climacteric fruits.

Climacteric fruit: harvested at full maturity stage and ripen after harvest. Maximum respiration starts immediately after harvest. Long shelf life (6-8 days) no need of sophisticated packing material as fruits are hard. e.g. Apple, Apricot, Avocado, Banana, Blue berry, Kiwi fruit, Mango, Papaya, Passion fruit, Peach, Peas, Muskmelon, Watermelon and tomato.

Non-climacteric fruits: Harvested at full ripening (90-95%) complete colour development. Rate of respiration is less than climacteric fruit. Difficult to transport need sophisticated packing material as fruits are soft and ripened. Difficult to transport. e.g. Cherry, cucumber, grapes, lemon, pineapple, mandarins *etc.*

3.1.2.1 Changes occurring during maturation and ripening (physiological and Biochemical)

1) Water: After harvest, during storage and ripening, fruit and vegetable lose water as a result of respiration transpiration and exchange of gas, resulting in water loss. Loss of H_2O depends upon the RH, temperature, anatomical structure and the rate of transpiration and respiration. When the loss is more than 5-10% fruit and vegetable start shrivel and become unusable.

2) Colour: The most common change is loss of green colour. It is due to degradation of chlorophyll structure. The degradation is due to pH, oxidative systems. The disappearance of chlorophyll is associated with the synthesis of pigments ranges from yellow to red.

3) CHO: CHO are important in attaining pleasing fruit flavours through sugar to acid balance, attractive colour and whole some texture.

4) Organic acids: the nonvolatile organic acids are among the major cellular constituents undergoing changes during the ripening of fruits. As the fruit ripens the acid content minimize and converts it in to sugar.

5) Proteins: Proteins are free amino acids, minor constituents of fruit and not have much role in determining eating quality.

6) Flavouring compounds: Aroma plays an important part in the development of optimal eating quality of fruit and vegetables. This is due to the synthesis of many volatile organic compounds during the ripening phase.

7) Enzymes: Many of the chemical and physical effects that occur during ripening of fruits are attributed to enzyme action.

3.1.2.2 Chemicals used for hastening and delay of ripening of fruit and vegetables

i. Chemicals that hasten ripening

1) **Ethylene:** Ethylene related compounds –CEPA-2 Chloro ethyl phosphoric acid, CPTA-2,4 Chloro phenyl friethyl amine. Used for pre and postharvest treatments of fruits.
2) **Acetylene and calcium chloride:** Calcium carbide treatment to generate acetylene to hasten fruit ripening in banana.
3) **Smoke treatment:** Burning and releasing smoke from leaves, twigs or straw will also hasten ripening in mango.
4) **2,4-D:** 2, 4 dichlorophenoxy acetic acid is used in ripening of Guava
2,4,5-T-2,4,5-trichlorophenoxy acetic acid used in Sapota.

ii. Chemicals used to delay ripening of fruit and vegetables

1) Cytokinins and Kinetins: Delays chlorophyll degradation and senescence of leafy vegetable.
2) Gibberellins: Post harvest treatments with GA3 retard ripening of tomato and bananas GA3 lowers respiratory rate, retards in climacteric fruits and delays the process of colour changes.
3) Growth retardants:
a) **MH** – prevents sprouting of onion bulbs and potato tubers. Also delays ripening of mango.
b) **Alar**: Reduce fruit firmness, fruit colour development and early maturation. It is applied before harvest. In lettuce it reduces senescence.
c) **CCC** (Cycocel)-2 chloroethyl – trimethyl ammonium chloride used in delaying of senescence of vegetables.
4) Delaying ripening process by skin coating (waxing):
Edible waxes are coated on fruits which prevent transpiration losses and minimize respiration rate.
a) Sugar wax along with emulsifier is melted and then boiling water is poured slowly to melted ingredients and prepares emulsion.

3.1.2.3 Factors affecting ripening of fruits and vegetables

- Respiration
- Transpiration / water loss
- Ripening Ethylene production
- Pathological stresses
- Mechanical stress

- Temperature stresses.

Respiration: It is the oxidative break down of more complex substrates normally present in cells such as sugars, starch and organic acids to simpler molecules CO_2 and H_2O.

Transpiration / water loss: Fruit and vegetables contain more than 87-95% water and the presence of moisture inside the tissue is responsible for maintenance of turgidity and succulence. Loss of moisture is direct loss to the traders. Hence, the fruit and vegetable are sold by weight.

Ripening: Ripening is associated with physical and biochemical irreversible process which leads to senescence and finally leads to death.

Ethylene: Ethylene is naturally produced gaseous plant growth regulator that has numerous effect on growth, development… and storage life of many fruits, vegetable and ornamentals.

Pathological stresses: Disease play major role. Fruit and vegetable affected with disease spoil early and minimize keeping quality/ shelf life.

Mechanical stress: Mechanical damage also affects fruit and vegetables.

Temperature: Temperature like chilling or freezing maximum temperature also affects the fruit and vegetables quality.

3.1.3 Senescence

Senescence is the last stage, characterized by natural degradation of the fruit or vegetable, as in loss of texture, flavour, etc. (senescence ends at the death of the tissue of the fruit). The deteriorative processes which ultimately lead to complete loss of organization and functioning of the plant or its parts are known as Senescence. Senescence occurs due to the deposition of waste material. In some plants the whole plant dies after flowering and producing seeds. This is called **whole plant senescence.** Example-annual plants like rice, wheat, beans, tomato, etc. In many other plants, parts above soil die each year and root system stays alive. This is called **organ senescence.**

Role of hormones in senescence: Abscissic acid and ethylene promote senescence of leaves but cytokinin delays senescence and helps leaves remain green for long period. Water stress caused by a deficiency of water manifests its damage as reductions in photosynthetic activity and increases in leaf senescence

Senescence is important at the organ level with respect to decreases in available photosynthetic area, flowering, and fruiting.

3.2 Determination of maturity

If the stage of maturity at which a fruit or vegetable should be harvested is important for its subsequent quality, storage and marketable life. Determination of maturity can be grouped into physical, chemical, physiological, computation, electronic *etc.* based on the principles used for measuring the various parameters.

3.2.1 Physical method

Skin colour: change of skin colour of many fruits at maturity (Toamto, Papaya, litchi, mango) colour charts are used for apple, tomato, peach *etc.* Instruments are also available for measuring colour of fruits and this is mostly used in harvested fruits.

Shape: the shape of fruit and vegetable can change during maturation. e.g. Banana becomes less angular

Size: Size is frequently used to determine at harvest. It is related to market requirement.

Firmness: As fruits mature and ripen the tissues become soften. The softening can be estimated by the finger feel of commodity (Firmness can be measured by penetrometer). (weight of fruit).

Specific gravity: It is measured through weight of solids or liquids. As fruits mature their specific gravity increases. This method is rarely practiced.

Aroma: Most fruits synthesis volatile chemicals as they ripen. Based on this we can determine whether fruit is ripe.

3.2.2 Chemical method:

a) Sugars, b) starch, c) acidity

a) Sugar: As the fruit ripens starch is broken down to sugars. Measurement of sugars indicate the stage of maturity or ripeness, sugar constitute the major portion of soluble solid of the fruit juice. Measurement of TSS is done on refractometer.

b) Starch: Starch content in developing fruit of pear and apple provides harvest maturity.

c) Acidity: The acidity of many type of fruit changes during maturing and ripening.

In citrus, mango, pineapple and many stage other fruits acidity progressively decrease as the fruit matures on the tree.

3.2.3 Physiological methods

Climacteric fruits, in which there is a distinct rise in respiration during ripening, can be sampled and kept at high temperature and respiration rate is measured. By this way we can predict the number of days will take for ripening stage if left on the tree.

Climacteric fruit: harvested at full maturity stage and ripen after harvest. Maximum respiration starts immediately after harvest. Long shelf life (6-8 days) no need of sophisticated packing material as fruits are hard. eg: Apple, Apricot, Avocado, Banana, Blue berry, Kiwi fruit, Mango, Papaya, Passion fruit, Peach, Peas, Muskmelon, Watermelon and tomato.

Non-climacteric fruits: Harvested at full ripening (90-95%) complete colour development. Rate of respiration is less than climacteric fruit. Difficult to transport need sophisticated packing material as fruits are soft and ripened. e.g. Cherry, cucumber, grapes, lemon, pineapple, mandarins etc.

3.2.4 Other methods of determining maturity

i. Computation method

The time required between flowering and fruit being ready for harvesting may be measured by 'heat units' or degree days in a particular environment.

ii. Electronic and other methods

Electronic colour sorter: used in packing houses to sort-out fruits on the basis of colour. eg: Apple, orange *etc.*

iii. Acosting and vibration test

The sound of fruit when tapped with knuckle of the finger, the sound heard changes during maturation and ripening- e.g. Watermelon and jack fruit.

3.3 Maturity indices

Maturity indices

The maturity index of a fruit provides an indication of its stage of development or maturation. Maturity indices are based on characteristics that are known to change as the fruit matures. Maturity indices for harvest can be either subjective or objective

3.3.1 Physical indices of maturity

Skin colour:

This factor is commonly applied to fruits, since skin colour changes as 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.

ii. Optical methods:

Light transmission properties can be used to measure the degree of maturity of fruits. These methods are based on the chlorophyll content of the fruit, which is reduced during maturation. The fruit is exposed to a bright light, which is then switched off so that the fruit is in total darkness. Next, a sensor measures the amount of light emitted from the fruit, which is proportional to its chlorophyll content and thus its maturity.

iii. 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.

iv. 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 callipers; this is referred to as the calliper grade.

v. Aroma:

Most fruits synthesize volatile chemicals as they ripen. Such chemicals give 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 a fruit is completely ripe, and therefore has limited use in commercial situations.

vi. Fruit opening:

Some fruits may develop toxic compounds during ripening, such as ackee tree fruit, which contains toxic levels of hypoglycine. 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 hypoglycine 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 hypoglycine '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 little health hazard, provided the seed and membrane portions are removed.

vii. 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.

viii. 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.

ix. Firmness:

A fruit may change in texture during maturation, especially during ripening when it may become rapidly softer. 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 texturometer 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, uses 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.

x. Juice content:

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

3.3.2 Chemical Indices of Maturity

a. **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 constitute the major portion of soluble solid of the fruit juice. Measurement of TSS is done on refractometer

b. **Starch:** Starch content in developing fruit of pear and apple provides harvest maturity.

c. **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.

3.4 Maturity standards

Maturity standards have been determined for many fruit, vegetable and floral crops. Harvesting crops at the proper maturity allows handlers to begin their work with the best possible quality produce. Produce harvested too early may lack flavor and may not ripen properly, while produce harvested too late may be fibrous or overripe. Pickers can be trained in methods of identifying produce that is ready for harvest. The following table (table 1.1.3) provides some examples of maturity indices.

Table 1.1.3 Examples of Maturity indices of some fruits

Index	Examples
Elapsed days from full bloom to harvest	Apples, pears
Mean heat units during development	Peas, apples, sweet corn
Development of abscission layer	Some melons, apples, feijoas
Surface morphology and structure	Cuticle formation on grapes, tomatoes Netting of some melons Gloss of some fruits (development of wax)
Size	All fruits and many vegetables
Specific gravity	Cherries, watermelons, potatoes
Shape	Angularity of banana fingers Full cheeks of mangos Compactness of broccoli and cauliflower
Solidity	Lettuce, cabbage, brussels sprouts
Textural properties	
Firmness	Apples, pears, stone fruits

Tenderness	Peas
Color, external	All fruits and most vegetables
Internal color and structure	Formation of jelly-like material in tomato fruits Flesh color of some fruits
Compositional factors	
Starch content	Apples, pears
Sugar content	Apples, pears, stone fruits, grapes
Acid content, sugar/acid ratio	Pomegranates, citrus, papaya, melons, kiwifruit
Juice content	Citrus fruits
Oil content	Avocados
Astringency (tannin content)	Persimmons, dates
Internal ethylene concentration	Apples, pears

Source: Kader, A. A. (1983)

Vegetables are harvested over a wide range of maturities, depending upon the part of the plant used as food.

The following table (table 2.1.3) provides some examples of maturity indices of vegetable crops.

Table 2.1.3 Examples of Maturity indices of vegetable crops

Crop		Index
Root, bulb and tuber crops		
Radish and carrot		Large enough and crispy (over-mature if pithy)

Potato, onion, and garlic		Tops beginning to dry out and topple down
Yam bean and ginger		Large enough (over-mature if tough and fibrous)
Green onion		Leaves at their broadest and longest
Fruit vegetables		
Cowpea, yard-long bean, snap bean, batao, sweet pea, and winged bean		Well-filled pods that snap readily
Lima bean and pigeon pea		Well-filled pods that are beginning to lose their greenness
Okra		Desirable size reached and the tips of which can be snapped readily
Upo, snake gourd, and dishrag gourd		Desirable size reached and thumbnail can still penetrate flesh readily (over-mature if thumbnail cannot penetrate flesh readily)
Eggplant, bitter gourd, chayote or slicing cucumber		Desirable size reached but still tender (over-mature if color dulls or changes and seeds are tough)
Sweet corn		Exudes milky sap from kernel if cut
Tomato		Seeds slipping when fruit is cut, or green color turning pink
Sweet pepper		Deep green color turning dull or red
Muskmelon		Easily separated from vine with a slight twist leaving clean cavity
Honeydew melon		Change in fruit color from a slight greenish white to cream; aroma noticeable
Watermelon		Color of lower part turning creamy yellow, dull hollow sound when thumped
Flower vegetables		
Cauliflower		Curd compact (over-mature if flower cluster elongates and become loose)
Broccoli		Bud cluster compact (over-mature if loose)
Leafy vegetables		
Lettuce		Big enough before flowering

Cabbage		Head compact (over-mature if head cracks)
Celery		Big enough before it becomes pithy

Source: Bautista, O.K. and Mabesa, R.C. (eds). (1977)

4.0 Conclusion

Maturity in virtually all crops can be divided into two types, physiological maturity which describes that period when sexually induced reproductive growth has ceased, and harvest maturity, where the seed, fruit, or other economically important organ of yield has reached a state of “ripeness” and can be removed from the parent plant for consumption. Maturity at harvest is the most important determinant of storage-life and final fruit quality. Maturity indices are important for deciding when a given commodity should be harvested to provide some marketing flexibilty and ensure the attainment of acceptable eating quality to the consumer. 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 vegetable 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

5.0 Summary

Lifecycle duration of all agricultural 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. Phytohormones play a vital role in plant maturation, beginning with germination and in some cases ending with product consumption. Maturation is closely associated with senescence. With respect to maturation, ethylene is known to stimulate flower opening, ripening, and abscission of leaves and fruit. 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 flavor and may not ripen properly, while produce harvested too late may be fibrous or overripe.

6.0Tutor Marked Assignment (TMA)

i. Distinguish physiological maturity from harvest maturity
ii. Describe the three stages of maturity in the life span of a plant
iii. Describe the physical indices of crop maturity
iv. State the chemical indices of crop maturity
v. Give the maturity standards of the following; tomato, okro, cabbage, water melon, carrot, cowpea and sweet corn
vi. Give two examples of each of the following:

    i. chemicals that delays ripening
    ii. chemicals that hasten ripening
    iii. climacteric fruits
    iv. non climacteric fruits

7.0 References and Further Readings

1. A.A. Kader (ed) (2002) Postharvest Technology of Horticultural Crops, third edition. University of California, ANR Publication 3311.
2. Bapat, V. A.,Trivedi, P. K., Gosh. A. and Sane. V. A 2010. Ripening of fleshy fruits: molecular insight and the role of ethylene. Biotechnol. Adv. 28:94-107
3. Bautista, O.K. and Mabesa, R.C. (eds). 1977. Vegetable Production. University of the Philippines at Los Banos.
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
6. Kader, A. A. 1983. Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
7. Kader A. A. 1999. Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
8. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469
9. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
10. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257, in:

11. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California, Division of Agriculture and Natural Resources, UC Bulletin 1914.
12. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
13. Saraswathy. S. and others. 2010. POST-HARVEST MANAGEMENT AND VALUE ADDITION OF HORTICULTURAL CROPS
14. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
15. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
16. http://www.postharvest.ucdavis.edu
17. http://www.fao.org/docrep
18. http://www.crcpress.com/product
19. http://www.actahort.org/books
20. http://sciencedirect.com/science/journal
21. http://www.stewartspostharvest.com

MODULE 2: POST HARVEST HANDLING OF CROP PRODUCTS

UNIT 1: INTRODUCTION TO POST HARVEST TECHNOLOGY

UNIT 2: CAUSES OF POST HARVEST LOSSES

UNIT 3 TECHNOLOGIES OF REDUCING POST HARVEST LOSSES

UNIT 4 POST-HARVEST TREATMENTS TO MINIMIZE PRODUCE CONTAMINATION AND TO MAXIMIZE QUALITY

UNIT 5 CROP PRODUCT PROCESSING

UNIT 1: INTRODUCTION TO POST HARVEST TECHNOLOGY

Table of Contents

1.0 Introduction

Despite the remarkable progress made in increasing food production at the global level, approximately half of the population in the Third World does not have access to adequate food supplies. There are many reasons for this, one of which is food losses occurring in the post-harvest and marketing system. Evidence suggests that these losses tend to be highest in those countries where the need for food is greatest. Both quantitative and qualitative food losses of extremely variable magnitude occur at all stages in the post-harvest system from harvesting, through handling, storage, processing and marketing to final delivery to the consumer. Estimates of the post-harvest losses of food grains in the developing world from mishandling, spoilage and pest infestation are put at 25 percent; this means that one-quarter of what is produced never reaches the consumer for whom it was grown, and the effort and money required to produce it are lost-forever. Fruit, vegetables and root crops are much less hardy and are most quickly perishable, and if care is not taken in their harvesting, handling and transport, they will soon decay and become unfit for human consumption.

Estimates of production losses in developing countries are hard to judge, but some authorities put losses of sweet potatoes, plantain, tomatoes, bananas and citrus fruit to as high as 50 percent, or half of what is grown. Reduction in this wastage, particularly if it can economically be avoided, would be of great significance to growers and consumers alike. To reduce these losses producers and handlers must first understand the biological and environmental factors involved in deterioration. And second, use post harvest techniques that delay senescence and maintain the best possible quality.

2.0 Objectives

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

- Explain what is post harvest technology and its relationship with other disciplines
- Have a clearer understanding of post-harvest physiological processes and mechanisms for their control
- Describe how temperature and relative humidity management are the most effective tool for extending the shelf life and quality of fresh horticultural commodities.
- Explain the procedure of controlling relative humidity and how to apply them in post harvest management of horticultural crops
- Describe the basic principles of food safety assurance
- Design measures to maintain or improve quality and reduce postharvest losses

3.0 What is Post-Harvest Technology?

Post-harvest technologies constitute an inter-disciplinary science and techniques applied to agricultural commodities after harvest for the purpose of preservation, conservation, quality control/enhancement, processing, packaging, storage, distribution, marketing, and utilization to meet the food and nutritional requirements of consumers in relation to their needs. Post-harvest technology stimulates agricultural production, prevents post-harvest losses, improves nutrition and adds value to agricultural products thereby opening new marketing opportunities and generating new jobs while stimulating growth of other related economic sectors. The process developing post-harvest technologies requires an interdisciplinary and multidimensional research approach, which includes scientific creativity, technological innovation, and commercial entrepreneurship and stakeholder inputs.

3.1 Importance of Post Harvest Technology

Importance of Post-harvest technology lies in the fact that it has capability to meet food requirement of growing population by eliminating avoidable losses making more nutritive food items from low grade raw commodity by proper processing and fortification, diverting portion of food material being fed to cattle by way of processing and fortifying low grade food and organic wastes and by-products into nutritive animal feed.

Post-harvest technology has potential to create rural industries. In India, where 80 percent of people live in the villages and 70 percent depend on agriculture have experienced that the process of industrialization has shifted the food, feed and fibre industries to urban areas. This process has resulted in capital drain from rural to urban areas, decreased employment opportunities in the rural areas, balance of trade in favour of urban sector and mismatched growth in economy and standard of living including the gap between rural and urban people. It is possible to evolve appropriate technologies, which can establish agricultural based rural industries.

The purpose of post harvest processing is to maintain or enhance quality of the products and make it readily marketable. Prime example of post harvest processing of agricultural products is rice, a major crop in India. Paddy is harvested and processed into rice. Experiments with paddy crop in farmer's field in India have shown that if the crop is harvested at 20 to 22 per cent moisture as traditionally done, the field yield is increased by 10 to 20 percent. Similar is the case with respect to wheat, jowar and other crops.

Importance of Post Harvest Technology

1. Proper handling, packaging, transportation and storage reduces the post harvest losses of fruit and vegetables. For every one percent reduction in loss will save 5 million tons of fruit and vegetable per year.

2. Processing and preservation technology helps to save excess fruit and vegetable during the glut season (off season).

3. The technology has become a necessity to improve the food safety and strengthen nations food security.

4. The technology helps to boost export of agricultural commodities in the form of preserved and value added products.

5. Presently mango, pineapple, citrus, grapes, tomatoes, peas, potato and cucumber being processed on a large scale.

3.2 Post Harvest Technology Procedures

3.2.1 Temperature management procedures

Temperature management is the most effective tool for extending the shelf life of fresh horticultural commodities. It begins with rapid removal of field heat by following one of the cooling methods: hydro-cooling, in-package icing, top icing, evaporative cooling, room cooling, forced air cooling, vacuum cooling or hydro-vacuum cooling. Cold storage facilities should be well engineered and adequately equipped. They should have good construction and insulation, including a complete vapour barrier on the warm side of the insulation; strong floors; adequate and well-positioned doors for loading and unloading; effective distribution of refrigerated air, sensitive and properly located controls; enough refrigerated coil surface to minimize the difference between the coil and air temperatures. Commodities should be stacked in cold rooms with spaces between pallets and room walls to ensure good air circulation. Storage rooms should not be loaded beyond their limit for proper cooling. In monitoring temperature, commodity temperature rather than room temperature should be measured.

3.2.2 Control of relative humidity (RH)

Relative humidity can influence water loss, decay development, incidence of some physiological disorders and uniformity of fruit ripening. Condensation of moisture on the commodity (sweating over long periods of time is probably more important in enhancing decay than is the RH of ambient air.proper relative humidity is 85-95% for fruits and 90-98% for vegetables except dry onions and pumpkins (70-75%). Some root vegetables can be best held at 95-100% RH.

Relative Humidity can be controlled by one or more of the following procedures:

- Adding moisture (water mist or spray steam,) to air by humidifiers
- Regulating air movement and ventilation in relation to the produce load in the cold storage room.
- Adding polythene liners in containers and plastic films for packaging.
- Wetting floors in storage rooms
- Adding crushed ice in retail displays for commodities that are not injured by ice.
- Sprinkling produce with water during retail marketing(use on leafy vegetables, cool season root vegetables, immature fruit vegetables such as snap beans, peas, sweet corn, summer squash.

3.3. Food Safety Assurance

Lapses in food safety do not only adversely impact the health of consumers. Flagrant safety errors have and will ruin the reputation and financial health of the offending food company. Food safety violations have caused the demise of companies and prison sentences for culpable executives. Worse yet, highly publicized safety lapses indict an entire industry, implicating the innocent majority together with the single guilty company.

During the past few years, food safety became and continuous to be the number one concern for the fresh produce industry. US Food and Drug Administration have published guides to minimize microbial food safety hazards for fresh fruits and vegetables. This guide is based on the following basic principles and practices and is practical in any developed or developing country.

Principle 1. Prevention of microbial contamination is favoured over reliance on corrective actions once contamination has occurred.

Principle 2. To minimize microbial food safety hazards in fresh produce, growers, packers or shippers should use good agricultural and management practices in those areas over which they have control.

Principle 3. Fresh produce can become microbiologically contaminated at any point along the farm to table food chain. The major source of microbial contamination of fresh produce is associated with human or animal faeces.

Principle 4. Whenever water comes in contact with produce, the quality of the water dictates the potential for contamination. Minimize the potential of microbial contamination from water used with fresh fruits and vegetables.

Principle 5. Practices using animal manure or municipal biosolid wastes should be managed closely to minimize the potential for microbial contamination of fresh produce.

Principle 6. Worker hygiene and sanitation practices during production, harvesting, sorting, packing and transport play a critical role in minimizing the potential for microbial contamination of fresh produce.

Principle 7. Follow all applicable local, state and country laws and regulations or corresponding or similar laws, regulations or standards for operations.

4.0 Conclusion

In this unit we have seen how Post-harvest technologies constitute an inter-disciplinary science and techniques applied to agricultural commodities after harvest for the purpose of preservation, conservation, quality control/enhancement, processing, packaging, storage, distribution, marketing, and utilization to meet the food and nutritional requirements of consumers in relation to their needs. Post-harvest technology stimulates agricultural production, prevents post-harvest losses, improves nutrition and adds value to agricultural products thereby opening new marketing opportunities and generating new jobs while stimulating growth of other related economic sectors. There is growing trend towards increased precision in temperature and relative humidity management to provide the optimal environment for fresh fruits and vegetables during cooling and storage.

5.0 Summary

Post-harvest technologies constitute an inter-disciplinary science and techniques applied to agricultural commodities after harvest for the purpose of preservation, conservation, quality control/enhancement, processing, packaging, storage, distribution, marketing, and utilization to meet the food and nutritional requirements of consumers in relation to their needs. Post-harvest technology stimulates agricultural production, prevents post-harvest losses, improves nutrition and adds value to agricultural products thereby opening new marketing opportunities and generating new jobs while stimulating growth of other related economic sectors.

6. Tutor Marked Assignment (TMA)

- **i.** Define post harvest technology
- ii. Describe the importance of post harvest technology
- iii. State the procedures of controlling relative humidity in storage of crop produce
- iv. Enumerate the principles of food safety assurance

7.0 References and Further Reading

1. A.A. Kader (ed) (2002) Postharvest Technology of Horticultural Crops, third edition. University of California, ANR Publication 3311.
2. Barkai-Golan, R. and Phillips, D.J. (1991) Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.
3. Bapat, V. A.,Trivedi, P. K., Gosh. A. and Sane. V. A 2010. Ripening of fleshy fruits: molecular insight and the role of ethylene. Biotechnol. Adv. 28:94-107
4. Bautista, O.K. and Mabesa, R.C. (eds). 1977. Vegetable Production. University of the Philippines at Los Banos.
5. Carol Thomas (2005) Post Harvest Handling of produce. News Letter of Inter American Institute for Cooperation in Agriculture (IICA)
6. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
7. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
8. Kader, A. A. 1983. Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
9. Kader A. A. 1999. Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
10. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469
11. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis

12. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
13. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257, in:
14. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California, Division of Agriculture and Natural Resources, UC Bulletin 1914.
15. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
16. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
17. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
18. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
19. Zinash Delebo OSUNDE (2008); Minimizing Postharvest Losses in Yam (*Dioscorea spp.*) Treatments and Techniques; Using Food Science and Technology to Improve Nutrition and Promote National Development, International Union of Food Science & Technology (2008)
20. http://www.postharvest.ucdavis.edu
21. http://www.fao.org/docrep
22. http://www.crcpress.com/product
23. http://www.actahort.org/books
24. http://sciencedirect.com/science/journal
25. http://www.stewartspostharvest.com

UNIT 2: CAUSES OF POST HARVEST LOSSES

Table of Contents

- **3.7.7 Biological pressures**

4.0 Conclusion

5.0 Summary

6.0 Tutor Marked Assignment (TMA)

7.0 References and Further Readings

1.0 Introduction

One of the sources of food insecurity in Africa is post harvest crop loss. In African countries pre and post-harvest crop losses are higher than the global average and impact more severely on already endangered livelihoods. It has been estimated that at least 10 percent of the continent's crop productivity is lost on and off farm. This is mainly because most subsistence farming communities to do not have access to appropriate technologies. A wide range of existing food processing technologies is not accessible to and adapted by African countries and their communities. Climatic conditions also contribute to crop losses. Floods, heavy rains, droughts and other related factors cause considerable post harvest crop loss. The majority of rural populations in developing countries has limited to no resources and solely depends on the agricultural sector for their subsistence, livelihood and revenue. Therefore, post harvest losses are often felt with greater magnitude then in developed nations. It is estimated that in the tropics each year between 25 and 40% of stored agricultural products is lost because of inadequate farm- and village-level storage. In the field and during storage the products are threatened by insects, rodents, birds and other pests. Moreover, the product may be spoiled by infection from fungi, yeasts or bacteria. In addition, for sowing seed it is important that the viability (its capacity to germinate) is maintained. In order to minimize the losses during storage it is important to know the optimum environmental conditions for storage of the product, as well as the conditions under which its attackers flourish. Post harvest loss results not only in the loss of the actual crop, but also losses in the environment, resources, labor needed to produce the crop and livelihood of individuals involved in the production process. According to the Food and Agricultural organization (FAO), post-harvest losses for grains amounted to over 200 million tones yearly, yet only about 20 million tones of grain are enough to feed adequately a population of 500 million for one year. In

Nigeria and other developing countries lost of agricultural products during storage could amount up to 30% for grains and up to 50% for root and tuber crops.

2.0 Objectives

By the end of this unit you should be able to

- Clearly define what is post harvest losses
- Describe the various causes of post harvest losses
- Differentiate between primary and secondary causes of post harvest loss
- Describe the different sites of loss
- Describe causes of loss on farm
- Describe the damages of crop produce in the marketing chain
- Describe the effects of the environment on food losses

3.0 Causes of Post Harvest losses

"**POST-HARVEST**" start at the moment of separation of the edible commodity from the plant that produced it by a deliberate human act with the intention of starting it on its way to the table. The post-harvest period ends when the food comes into the possession of the final consumer.

"**LOSS**" means any change in the availability, edibility, wholesomeness or quality of the food that prevents it from being consumed by people.

Significant volumes of grain in developing countries are lost after harvest, aggravating hunger and resulting in expensive inputs—such as fertilizer, irrigation water, and human labor—being wasted. During postharvest operations, there may be losses of both cereal quantity and quality. Qualitative Post Harvest Losses can lead to a loss in market opportunity and nutritional value; under certain conditions, these may pose a serious health hazard if linked to consumption of aflatoxin-contaminated grain. The causes of loss are many and varied.

- *Technical causes* may include harvesting methods; handling procedures; drying techniques and moisture levels; types of storage or lack thereof; filth or contamination; attacks by rats, birds, and other pests; insect damage; and infestation by food-borne pathogens.

- *Governance-related causes* can include poor sales, procurement, storage, marketing and distribution policies or practices; absence of mechanisms for dealing with cash flow needs (such as warehouse receipts systems, or WRS); mismanagement or malfeasance in handling grain stocks and associated financing; or difficulty in dealing with the ownership, control, and payment aspects of grain storage and price stabilization programs. Overall, food losses contribute to high food prices by removing part of the food supply from the market. They also have an impact on environmental and climate change, as land, water, and non-renewable resources such as fertilizer and energy are used to produce, process, handle, and transport food that no one consumes
- Post harvest losses occur during harvesting and handling due to grain shattering, due to spillage during transport and also result from biodeterioration at all steps in the post harvest chain including storage. The principle agents of biodeterioration are moulds, insects, rodents and birds. A variety of insects pests, like the larger grain borer are one cause of post harvest losses. They start their attack in the mature crop and carry over into storage.
- Grains may be lost in the pre-harvest, harvest and post-harvest stages. Pre-harvest losses occur before the process of harvesting begins, and may be due to insects, weeds and rusts. Harvest losses occur between the beginning and completion of harvesting, and are primarily caused by losses due to shattering. Post-harvest losses occur between harvest and the moment of human consumption. They include on-farm losses, such as when grain is threshed, winnowed and dried, as well as losses along the chain during transportation, storage and processing. Important in many developing countries, particularly in Africa, are on-farm losses during storage, when the grain is being stored for auto-consumption or while the farmer awaits a selling opportunity or a rise in prices.

There are so many causes for losses in the post-harvest food chain that it helps to classify them into 2 groups and a numb or of sub-groups

3.1. 1 Primary Causes of Loss

These are those causes that directly affect the food. They may be classified into the following groups

a. Biological. Consumption of food by rodents, birds, monkeys and other large animals causes direct disappearance of food. Sometimes the level of contamination of food by the excreta, hair and feathers of animals and birds is so high that the food is condemned for human consumption. Insects cause both weight losses through consumption of the food and quality losses because of their frass, webbing, excreta, heating, and unpleasant odours that they can impart to food.
b. Microbiological. Damage to stored foods by fungi and bacteria. Micro-organisms usually directly consume small amount e of the food but they damage the food to the point that it becomes unacceptable because of rotting or other defects. Toxic substances elaborated by molds (known as mycotoxins), cause some food to be condemned and hence lost. The beat known of the mycotoxins is aflatoxin (a liver carcinogen), which is produced by the mold Aspergillus flavus. Another mycotoxin which is found in some processed apple and pear products is patulin, which is formed in the apple by rotting organisms such as Penicillium expansum which infect fresh apples before they are processed.
c. Chemical. Many of the chemical constituents naturally present in stored foods spontaneously react causing loses of colour, flavour, texture and nutritional value. An example is the Maillard relation' that causes browning and dicolouration in dried fruits and other product a There can also be accidental or deliberate contamination of food with harmful chemicals such as pesticides or obnoxious chemicals ouch as lubricating oil
d. Biochemical reactions. A number of enzyme-activated reactions can occur in foods in storage giving rise to oft-flavours, discolouration and softening. One example of this problem is the unpleasant flavours that develop in frozen vegetables that have not been blanched to inactivate these enzymes before freezing.
e. Mechanical. Bruising, cutting' excessive pooling or trimming of horticultural products are causes of loss.
f. Physical. Excessive or insufficient heat or cold can spoil foods. Improper atmosphere in closely confined storage at times causes losses.
g. Physiological. Natural respiratory losses which occur in all living organisms account for a significant level of weight lose and' moreover, the process generates heat. Changes which occur during ripening, senescence, including wilting, and termination of dormancy (e.g., sprouting) may increase the susceptibility of the commodity to mechanical damage or infection by pathogens. A reduction in nutritional level and

consumer acceptance may also arise with these changes. Production of ethylene results in premature ripening of certain crops.

h. Psychological. Human aversion, such as "I don't fancy eating that today". In some cases food will not be eaten because of religious taboos.

Microbiological, mechanical and physiological factors cause moat of the losses in perishable crops.

3.1.2 Secondary Causes of Loss

These are those that lead to conditions that encourage a primary cause of loss. They are usually the result of inadequate or non-assistant capital expenditures, technology and quality control. Some examples are:

a. Inadequate harvesting, packaging and handling skills.
b. Lack of adequate containers for the transport and handling of perishables.
c. Storage facilities inadequate to protect the food.
d. Transportation inadequate to move the food to market before it spoils.
e. Inadequate refrigerated storage.
f. Inadequate drying equipment or poor drying season.
g. traditional processing and marketing systems can be responsible for high losses.
h. Legal standards can affect the retention or rejection of food for human use by being too lax or unduly strict.
i. Conscientious, knowledgeable management is essential for maintaining tool in good condition during marketing and storage.
j. Bumper crops can overload the post-harvest handling system or exceed the consumption need and cause excessive wastage.

3.2 Sites of losses

Losses may occur anywhere from the point where the food has been harvested or gathered up to the point of consumption. For the sake of convenience the losses can be broken down into the following sub-headings:

a. Harvest. The separation of the commodity from the plant that produced it. In the case of roots, tubers and bulbs the commodity is lifted out of the soil.
b. Preparation. The preliminary separation or extraction of the edible from the non-edible portion, e.g., the peeling of fruits and vegetables.
c. Preservation is the prevention of lose and spoilage of foods. For example, the sun-drying of fruit, the use of refrigeration and the use of fungicides to inhibit mold growth in fruits.
d. Processing is the conversion of edible food into another form more acceptable or more convenient to the consumer, for example, the manufacture of fruit juice and the canning of fruits and vegetables.
e. Storage is the holding of foods until consumption. Most storage is common storage (ambient temperature) but there are extensive storage capacities that can hold food under refrigerated or controlled atmosphere conditions.

a. Transportation. All forms of transportation are used to convey foods from the point of production to the ultimate point of consumption.

Post-harvest losses in fresh root/tuber crops have their origin in mechanical damage, physiological processes, and infection by decay organisms and, occasionally, pest infestation. The losses caused by these processes may occur during all stages of the food supply system from crop maturity, through harvesting, transportation and storage. The degree of lose associated with these factors is determined by the plant material involved, the prevailing environmental conditions and management of the food supply system. The major causes of lose in roots and tubers and the sites where they occur are summarized below:

3.3 Magnitude of losses

Reliable statistics on losses are few. It is possible to find individual cases with losses ranging from 0% to 100%. The extent of losses is highly variable depending on a number of conditions. Stable foods such as cereal grains can be stored in good condition for several years, whereas perishable foods such as fruit and vegetables, spoil quickly unless given special treatment such as canning and freezing. The longer the time the food is stored the more opportunity there is for losses of all kinds to occur. Perishable crops generally suffer from higher losses than the cereals.

A number of figures for the extent of loss is quoted in scientific literature and by the communications media, but much of this information is unreliable because the amount of loss has been estimated and has not been obtained by actual measurements. There is often the temptation to cite "worst case" figures to dramatize the problem.

Another problem is that even some of the figures that have been obtained by careful measurements are manipulated for various reasons. In some cases there is the temptation to exaggerate the figures of loss, particularly if there is a prospect that high figures of loss will prompt aid from donors. In other cases there is a temptation to minimize loss figures in order to prevent the embarrassment of acknowledging the magnitude of losses, or for political, financial or trading reasons.

Another precaution that needs to be taken in assessing overall losses is to ensure that the arithmetic of calculating loss figures is correct. The extent of losses can be unwittingly exaggerated unless the arithmetical calculations are correctly performed.

The pattern of losses varies widely from country to country. There is a marked contrast between the site of major losses in developed countries and developing countries. In a typical developed country losses may be fairly high during harvesting because the agricultural machinery that is used to harvest the crops leaves some of the commodity in the field and mechanically damages some of it. Considerable quantities of foods a may be discarded at the point of harvest because they are of the wrong size, shape or colour. These are planned losses. In developing countries harvest losses are usually lower because most of the crop is handpicked. The amount of material rejected in developing countries is less because the expectation of quality and uniformity is generally lower than for developed countries.

In developed countries losses are generally small during processing, storage and handling because of the efficiency of the equipment, good quality storage facilities, and close control of critical variables by a highly knowledgeable cadre of managers. In contrast, in developing countries losses in processing, storage and handling tend to be rather high because of poor facilities and frequently inadequate knowledge of methods to care for the food properly.

3.4 On-farm causes of loss

There are numerous factors affecting post-harvest losses, from the soil in which the crop is grown to the handling of produce when it reaches the shop. Pre-harvest production practices may seriously affect post-harvest returns. Plants need a continuous supply of water for photosynthesis and transpiration. Damage can be caused by too much rain or irrigation, which can lead to decay; by too little water; and by irregular water supply, which can, for example, lead to growth cracks. Lack of plant food can affect the quality of fresh produce, causing stunted growth or discoloration of leaves, abnormal ripening and a range of other factors. Too much fertilizer can harm the development and post-harvest condition of produce. Good crop husbandry is important for reducing losses. Weeds compete with crops for nutrients and soil moisture. Decaying plant residues in the field are also a major loss factor.

3.5 Causes of loss after harvest

Fruits and vegetables are living parts of plant and contain 65 to 95 percent water. When food and water reserves are exhausted, produce dies and decays. Anything that increases the rate at which a product's food and water reserves are used up increases the likelihood of losses. Increases in normal physiological changes can be caused by high temperature, low atmospheric humidity and physical injury. Such injury often results from careless handling, causing internal bruising, splitting and skin breaks, thus rapidly increasing water loss.

Respiration is a continuing process in a plant and cannot be stopped without damage to the growing plant or harvested produce. It uses stored starch or sugar and stops when reserves of these are exhausted, leading to ageing. Respiration depends on a good air supply. When the air supply is restricted fermentation instead of respiration can occur. Poor ventilation of produce also leads to the accumulation of carbon dioxide. When the concentration of carbon dioxide increases it will quickly ruin produce.

Fresh produce continues to lose water after harvest. Water loss causes shrinkage and loss of weight. The rate at which water is lost varies according to the product. Leafy vegetables lose water quickly because they have a thin skin with many pores. Potatoes, on the other hand, have a thick skin with few pores. But whatever the product, to extend shelf or storage life the rate of water loss must be minimal. The most significant factor is the ratio of the surface area of the fruit or vegetable to its volume. The greater the ratio the more rapid will be the loss of water. The rate of loss is related to the difference between the water vapour pressure inside the produce and in the air. Produce must therefore be kept in a moist atmosphere.

Diseases caused by fungi and bacteria cause losses but virus diseases, common in growing crops, are not a major post-harvest problem. Deep penetration of decay makes infected produce unusable. This is often the result of infection of the produce in the field before harvest. Quality loss occurs when the disease affects only the surface. Skin blemishes may lower the sale price but do not render a fruit or vegetable inedible. Fungal and bacterial diseases are spread by microscopic spores, which are distributed in the air and soil and via decaying plant material. Infection after harvest can occur at any time. It is usually the result of harvesting or handling injuries.

Ripening occurs when a fruit is mature. Ripeness is followed by 64and breakdown of the fruit. The category "fruit" refers also to products such as aubergine, sweet pepper and tomato. **Non-climacteric fruit** only ripen while still attached to the parent plant. Their eating quality suffers if they are harvested before fully ripe as their sugar and acid content does not increase further. Examples are citrus, grapes and pineapple. Early harvesting is often carried out for export shipments to minimise loss during transport, but a consequence of this is that the flavour suffers. **Climacteric** fruit are those that can be harvested when mature but before ripening has begun. These include banana, melon, papaya, and tomato. In commercial fruit marketing the rate of ripening is controlled artificially, thus enabling transport and distribution to be carefully planned. Ethylene gas is produced in most plant tissues and is important in starting off the ripening process. It can be used commercially for the ripening of climacteric fruits. However, natural ethylene produced by fruits can lead to in- storage losses. For example, ethylene destroys the green colour of plants. Leafy vegetables will be damaged if stored with ripening fruit. Ethylene production is increased when fruits are injured or decaying and this can cause early ripening of climacteric fruit during transport

3.6 Damage in the marketing chain

Fruits and vegetables are very susceptible to mechanical injury. This can occur at any stage of the marketing chain and can result from poor harvesting practices such as the use of dirty cutting knives; unsuitable containers used at harvest time or during the marketing process, e.g. containers that can be easily squashed or have splintered wood, sharp edges or poor nailing; overpacking or underpacking of containers; and careless handling of containers.

Resultant damage can include splitting of fruits, internal bruising, superficial grazing, and crushing of soft produce. Poor handling can thus result in development of entry points for moulds and bacteria, increased water loss, and an increased respiration rate. Produce can be damaged when exposed to extremes of temperature. Levels of tolerance to low temperatures are importance when cool storage is envisaged. All produce will freeze at temperatures between 0 and -2 degrees Celsius. Although a few commodities are tolerant of slight freezing, bad temperature control in storage can lead to significant losses

Some fruits and vegetables are also susceptible to contaminants introduced after harvest by use of contaminated field boxes; dirty water used for washing produce before packing; decaying, rejected produce lying around packing houses; and unhealthy produce contaminating healthy produce in the same packages.

Losses directly attributed to transport can be high, particularly in developing countries. Damage occurs as a result of careless handling of packed produce during loading and unloading; vibration (shaking) of the vehicle, especially on bad roads; and poor stowage, with packages often squeezed in to the vehicle in order to maximise revenue for the transporters. Overheating leads to decay, and increases the rate of water loss. In transport it can result from using closed vehicles with no ventilation; stacking patterns that block the movement of air; and using vehicles that provide no protection from the sun. Breakdowns of vehicles can be a significant cause of losses in some countries, as perishable produce can be left exposed to the sun for a day or more while repairs are carried out.

At the retail marketing stage losses can be significant, particularly in poorer countries. Poor-quality markets often provide little protection for the produce against the elements, leading to rapid produce deterioration. Sorting of produce to separate the saleable from the unsaleable can result in high percentages being discarded, and there can be high weight loss from the trimming of leafy vegetables. Arrival of fresh supplies in a market may lead to some existing, older stock being discarded, or sold at very low prices.

3.7 Effects of the environment on food losses

The environmental conditions under which foods are stored and processed can have a major effect on the keeping quality of the foods and the amount that is lost. The major environmental influences on the keeping quality of foods are the following:

3.7.1 Temperature.

In general, the higher the temperature the shorter the storage life of horticultural products and the greater the amount of lose within a given time, as most factors that destroy the produce or lower its quality occur at a faster rate as the temperature increases. This statement applies to the rate of growth of spoilage microorganisms, the rate of indigenous physiological change and physical processes such as water loss and wilting, Figure 1 show. changes in the quality of lettuce and asparagus during storage at different temperatures, Lettuce stored at 25 C becomes unsaleable within 7 days, while lettuce stored at 10 C will reach the unsaleable condition in approximately 18 days and lettuce stored at 0°C requires 35 days to reach the point of being unsaleable. For asparagus the loss of quality occurs at a more rapid rate than lettuce, reaching the point of being unsaleable in 3 days when stored at 25°C. Figure 1 is a clear demonstration of the rationale for the extensive cold storage facilities that are used for storing horticultural produce.

3.7.2 Humidity.

There is movement of water vapour between a food and its surrounding atmosphere in the direction towards equilibrium water activity in the food and the atmosphere, A moist food will give up moisture to the air while a dry food will Absorb moisture from the air. Fresh horticultural products have a high moisture content and need to be stored under conditions of high relative humidity in order to prevent moisture loss and wilting, exceptions to this being onions and garlic. Dried or dehydrated products need to be stored under conditions of low relative humidity in order to avoid absorbing moisture to the point where mold growth occurs.

3.7.3 Solar Radiation.

The solar radiation that falls upon foods held in direct sunlight increases the temperature above the ambient temperature. The amount of increase in temperature depends on the intensity of the radiation, the size and shape of the food' and the duration of exposure to the direct rays of the sun. The intensity of solar radiation depends upon latitude, altitude, season of the year, time of day, and degree of cloud cover. Under clear skies it is most intense when the sun is most directly overhead. Hence the intensity of radiation is greater in tropical zones than in temperate zones. As discussed above, a high temperature is deleterious to food quality and increases wastage. It is ironic to note that, in the temperate climates where the intensity of solar radiation is moderate, almost all food is kept inside under cover whereas in tropical climates, where solar radiation is much higher, considerable quantities of food can often be found in the direct rays of the sun deteriorating in quality at a rapid rate.

3.7.4 Altitude.

Within given latitude the prevailing temperature is dependent upon the elevation when other factors are equal. There is on the average a drop in temperature of 6.5°C for each Km increase in elevation above sea level. Storing food at high altitudes will therefore tend to increase the storage life and decrease the losses in food provided it is kept out of the direct rays of the sun.

3.7.5 Atmosphere.

The normal atmosphere contains by volume, approximately 78% nitrogen, 21% oxygen, 1% argon, 0.03% carbon dioxide' various amounts of water vapour and traces of inert gases. Modifying the atmosphere can improve the shelf life and reduce wastage of certain foods.

One type of controlled atmosphere storage (CA) is refrigerated storage in which the level of oxygen is reduced to about 3% with the carbon dioxide content being raised to 1 to 5%, depending on the commodity. This CA storage may double the storage life over that of regular cold storage for certain varieties of apples and pears by slowing down the natural rate of respiration.

Many fruits, the "climacteric fruits", generate ethylene gas during ripening and the presence of this gas accelerates the rate of ripening. If the ethylene is removed from the atmosphere surrounding these fruits as it is generated, their storage life may be extended. Experiments have shown that placing such fruits in a fairly gas-tight container with potassium permanganate, which absorbs ethylene gas, can substantially extend the storage life even at ambient temperature.

"Modified atmosphere storage" is another type of controlled atmosphere storage. This term denotes storage of horticultural products in a beneficial atmosphere other than air that is not under as close regulation as in CA storage. Modified atmosphere storage can be obtained in boxes of pears, apples, and cherries that are lined with polyethylene film which acts as a barrier to the escape of carbon dioxide and the ingress of oxygen. Another method of obtaining modified atmosphere storage is by the addition of dry ice which increases the carbon dioxide in the atmosphere to some extent

3.7.6 Time.

The longer the time the food is stored the greater is the deterioration in quality an' the greater is the chance of damage and loss. Hence storage time is a critical factor in loss of foods, especially those that have a short natural shelf life. The time involved from harvest to consumption of perishable commodities is much shorter than that from planting to harvest. While production time could take about several years for fruit trees, and generally about three to four months for vegetables, the duration of post-harvest handling could be as abort as one day to a few weeks. Any improvement in post-harvest handling treatments would therefore involve less risk and would be more economical than improvements in production.

3.7.7 Biological pressures.

Bacteria and fungi are always present in the atmosphere to contaminate food and cause spoilage should conditions favour their growth. However, it should be emphasized that the contamination or inoculation process with bacteria and fungi occurs to an equal extent during the harvesting process. Soil organisms as well as foliage pathogens can be introduced. Bacteria that cause disease in plants are not usually introduced from the air par so except in aerosols. Micro-organisms can multiply very rapidly whenever conditions are favourable for growth. The only foods that are free from micro-organisms are those that have been thermally processed, such as canned goods.

A similar situation occurs with insects. Insects are in the field and can accompany foods as they are brought from the field into storage. Most of the stored products' insects can increase is number by a factor of 10 to 50 times par month under favourable conditions. Stored food insects are ubiquitous, hiding in storage facilities and moving with stored foods when they are moved. Consequently we can assume that foods can become infested with insect pests at any time unless special precautions are taken.

Rodents and sometimes birds can exert biological pressures similar to those of insects and micro-organisms. The great capacity of living organisms for multiplication by geometric increase generates heavy biological pressures upon stored foods.

4.0 Conclusion

The causes of loss are many and varied. *Technical causes* may include harvesting methods; handling procedures; drying techniques and moisture levels; types of storage or lack thereof; filth or contamination; attacks by rats, birds, and other pests; insect damage; and infestation by food-borne pathogens. *Governance-related causes* can include poor sales, procurement, storage, marketing and distribution policies or practices; absence of mechanisms for dealing with cash flow needs (such as warehouse receipts systems, or WRS); mismanagement or malfeasance in handling grain stocks and associated financing; or difficulty in dealing with the ownership, control, and payment aspects of grain storage and price stabilization programs. Overall, food losses contribute to high food prices by removing part of the food supply from the market. They also have an impact on environmental and climate change, as land, water, and non-renewable resources such as fertilizer and energy are used to produce, process, handle, and transport food that no one consumes

Pre-harvest production practices may seriously affect post-harvest returns. Plants need a continuous supply of water for photosynthesis and transpiration. Damage can be caused by too much rain or irrigation, which can lead to decay; by too little water; and by irregular water supply, which can, for example, lead to growth cracks. Lack of plant food can affect the quality of fresh produce, causing stunted growth or discoloration of leaves, abnormal ripening and a range of other factors. Too much fertilizer can harm the development and post-harvest condition of produce. Good crop husbandry is important for reducing losses.

5.0 Summary

Post harvest losses occur during harvesting and handling due to grain shattering, due to spillage during transport and also result from biodeterioration at all steps in the post harvest chain including storage. The principle agents of biodeterioration are moulds, insects, rodents and birds. A variety of insects pests, like the larger grain borer are one cause of post harvest losses. They start their attack in the mature crop and carry over into storage. There are so many causes for losses in the post-harvest food chain that it helps to classify them into two groups primary and secondary causes of loss. The environmental conditions under which foods are stored and processed can have a major effect on the keeping quality of the foods and the amount that is lost. The major environmental influences on the keeping quality of foods are the following: temperature, humidity, radiation, time, ethylene, atmosphere and biological pressure

6.0Tutor Marked Assignment (TMA)

i. State the major causes of post harvest losses
ii. Explain the major elements of primary causes of loss
iii. Discuss on farm causes of loss
iv. What are the causes of loss in the marketing chain
v. Describe the effect of environment on post harvest loss of produce
vi. Describe the major causes of loss after harvest
vii. Describe the effects of temperature on food losses

7.0 References and Further Readings

1. A.A. Kader (2002). Postharvest Technology of Horticultural Crops, third edition. University of California , ANR Publication 3311
2. Barkai-Golan, R. and Phillips, D.J. (1991) Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.
3. Carol Thomas (2005) Post Harvest Handling of produce. News Letter of Inter American Institute for Cooperation in Agriculture (IICA)
4. D.L. Proctor, (1994) **Grain storage techniques** Evolution and trends in developing countries **FAO AGRICULTURAL SERVICES BULLETIN No. 109**
5. Jelle Hayma. 2003 The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
6. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. p.455-469
7. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation.
8. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
9. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
10. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa World Bank Report No. 60371-AFR. April 2011
11. O. Charles Aworh (2008); The Role of Traditional Food Processing Technologies In National Development: the West African Experience. International Union of Food Science & Technology (2008)
12. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California , Division of Agriculture and Natural Resources, UC Bulletin 1914.

13. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
14. http://postharvest.ucdavis.edu
15. http://www.fao.org/docrep/
16. http://www.crcpress.com/product
17. http://www.actahort.org/books
18. http://sciencedirect.com/science/journal
19. http://www.stewartspostharvest.com

UNIT 3 TECHNOLOGIES OF REDUCING POST HARVEST LOSSES

Table of Contents

5. 0 Summary

6. 0Tutor Marked Assignment (TMA)

7.0 References and Further Reading

1.0 Introduction

Attention to the concept of post-harvest food loss reduction as a significant means to increase food availability was drawn by the World Food Conference held in Rome in 1974. This recognition of the potential value of post-harvest loss reduction has found practical expression in the continuing debate among a number of International Organizations and Institutions. As a result several initiatives at the international level have been taken with the special aim of making a concerted effort to reduce unnecessary losses at all the post-harvest stages of the food production process.

There are a wide range of post harvest technologies that can be adopted to improve losses throughout the process of pre-harvest, harvest, cooling, temporary storage, transport, handling and market disbursement.

The major technologies for reducing losses in horticultural products are listed below

2.0 Objectives

At the end of this unit you would be able to:

- Identify the different technologies that could be applied to reduce post harvest loss
- Describe each of the listed technologies for reducing post harvest losses
- Apply some of these technologies in reducing post harvest losses of produce
- State the principles of refrigeration of perishable crops
- Describe controlled Atmosphere Storage

3.0 Technology of Reducing Post harvest losses

3.1 Gentle handling

Because of their soft texture all horticultural products should be handled gently to minimize bruising and breaking of the skin. Bruising renders the product unsaleable to most people although it usually has minor effect upon the nutritional value. The skin of horticultural products is an effective barrier to most of the opportunistic bacteria and fungi that cause rotting of the tissues. Breaking of the skin also stimulates physiological deterioration and dehydration. Careful digging and movement of roots and tubers significantly reduces postharvest losses. Careful handling of fruits and vegetables to minimize bruising and breaking of the skin likewise is a well-known method of reducing postharvest losses as is the provision of adequate shipping containers to protect the produce from bruising' and puncturing of the skin. Reducing the number of times the commodity is handled reduces the extent of mechanical damage.

3.2 Temperature control

It is well known that cooling horticultural produce extends storage life by reducing the rate of physiological change and retarding the growth of spoilage fungi and bacteria. Cooling is the foundation of quality protection. Since every degree reduction from ambient temperature increases storage life' every form of cooling is beneficial even if it is not optimum cooling, i.e.' simple low-cost cooling or refreshing the product is better than no cooling at all.

The optimum storage temperature for most temperate horticultural crops is close to **0°C.** If they are cooled slightly below this temperature they freeze and suffer from "freezing injury" and spoil quickly. Most tropical horticulture crops however can be injured oven at temperatures above freezing point. This is called "**chilling injury**" and causes rapid deterioration in quality. The optimum storage temperature for most tropical horticulture crops is between **7 to 10°C;** for yams and bananas it is about **15°C.**

Although refrigerated storage is not often appropriate for some commodities such as yams, it should be considered an important element in the temperature management of a wide range of perishable crops because it gives the most positive and direct control of temperature. The popularity of refrigerated storage in some countries has suffered setbacks duo to occasional poor design of units and bad management. This has sometimes resulted in the impression that refrigerated storage is costly and unsuited for use in developing countries which is not necessary the case. Good cosign and proper management are essential ingredients in considering the introduction of refrigeration techniques as are the supporting infrastructures available within the post-harvest system. When studied on a case-by-case basis it seems likely that refrigerated storage will continue to find many successful applications to the needs of developing countries.

3.3 Principles of Refrigeration of perishable crops

There are tour basic principles which must be correctly applied for successful refrigeration of perishable crops:

i. Select only healthy products. Refrigeration does not destroy pathogens responsible for product deterioration but only slows their activity; it does not improve product quality but only maintains it. A damaged product will deteriorate more quickly than a healthy one even in refrigerated storage; hence it is pointless to submit poor quality produce to refrigeration. In addition storage under refrigeration increases the cost to the product. The storage therefore of low grade diseased produce frequently cannot achieve an adequate economic return.

ii. Timely cooling: Since refrigeration slows the development of micro-organisms and physiological changes responsible for deterioration of perishable crops, it is obvious that cooling should be applied as soon as possible after harvest. The technique of pre-cooling was developed to fill this need by cooling produce soon after harvesting down to a temperature appropriate to that product.

iii. Adhere closely to optimal conditions for temperature and relative humidity. It is well known that refrigeration provides maximum storage life it these two parameters are correctly adhered to. This fact is especially important for tropical fruits and vegetables because their optimum storage temperatures vary considerably between varieties and even between producing areas. One of the main roles of research centres in tropical countries should be to define optimum storage conditions for commodities grown under tropical conditions. There is a need to evaluate the limitations of storage of these commodities under a range of temperature conditions and to consider the implications and problems of product compatibility under conditions of mixed commodity storage.

iv. Uninterrupted cooling: Refrigeration should be applied from the point of harvest through to the point of consumption where maximum post-harvest life with high product quality is justified. This is the well known concept of the "cold chain".

3.4 High humidity

High humidity retards wilting and maintains the product in better condition. Most horticultural products store best in an atmosphere that has a relative humidity of 90%

3.5 Waxing of the surface

Waxing the surface of horticultural products is a treatment used on a number of commodities including citrus fruits, apples, rutabagas and cucumbers. It retards the rate of moisture loss, and maintains turgor and plumpness and may modify the internal atmosphere of the commodity, and is performed primarily for its cosmetic effect; the wax imparts a gloss to the skin and gives the produce a more shiny appearance than the unwaxed commodity. Sometimes antiwaxing is a techniques that could probably be used more widely in developing countries with advantage. In some countries indigenous waxes may be suitable for this purpose. For example, experiments in Colombia have shown that waxing of cassava can extend the storage life from 2 to 3 days up to about 30 days by preventing discolouration in the vascular tissue. Work in India has also demonstrated the efficacy of indigenously produced wax emulsion formulations in extending the storage life of different fruits and vegetables

3.6 Controlled atmosphere storage

Controlled atmosphere storage consists of placing a commodity in a gas-tight refrigerated chamber and allowing the natural respiration of the fruit to decrease the oxygen and increase the carbon dioxide content of the atmosphere in the chamber. Typically, for storage of apples the oxygen content is lowered to about 3% and carbon dioxide is allowed to increase to 1 to 5%. This atmosphere can extend the storage life of apples by several months and allows fresh apples to be marketed every month of the year. These technologies require expensive storage chambers and close supervision of the composition of the atmosphere and are unsuited for widespread use in less developed countries.

Some roots and tubers are stored in pits in the ground, known as "clamp storage". Well designed clamps tend to change the atmosphere to some extent by reducing oxygen and increasing the carbon dioxide content. Modified atmosphere storage would probably be effective for a limited number of commodities in developing countries especially if coupled with low temperature storage. Research has recently shown that short pre-storage exposure to high carbon dioxide and low oxygen atmosphere of vegetables can extend the storage life of commodities even at ambient temperature.

The now technology of **hypobaric storage** is emerging which maintains reduced pressure in the refrigerated storage chamber by means of vacuum pumps. In this system the commodity is placed in a flowing stream of highly humidified air which is maintained at a reduced pressure and controlled temperature. Under these conditions, Bases released by the commodity that limits its storage life, are flushed away. Reports indicate that the storage life of certain fruits and vegetables is extended substantially by this procedure. The economic feasibility of this type of controlled atmosphere storage is presently being tested. This is an energy-intensive and capital-intensive technology and is perhaps unsuited for less developed countries.

3.7 Field factors

Maturity at time of harvest is an important factor in the keeping quality of horticultural products. Commodities that are harvested in an immature state not only have poor eating quality but may tend to shrivel in storage and be more susceptible to storage disorders. When picked too mature the commodity is soft or fibrous, the flesh breaks down more quickly and it has a shorter storage life. There is an optimum time of harvest to give maximum storage life for fruits, vegetables and tubers.

It is reported that the storage life of fresh cassava can be greatly extended by leaving part of the stalk attached to the tubers at harvest time. There are a number of other field factors that affect losses and these should be utilized as much as possible.

3.8 Suberization and curing

Potatoes, sweet potatoes, yams and several other roots and vegetables have the ability to heal skin wound when held at moderately warm conditions and high humidity for several days after harvest. The self-healing of wounds, cute and bruises is known as **curing.** There are two steps in the curing process. First is suberization - the production of suberin and its deposition in cell walls. The second is the formation of a cork cambium and production of cork tissue in the bruised area. The new cork tissue seals the cut or bruised areas and helps prevent the entrance of decay organisms. The healing of injuries received in harvesting and handling prolongs the storage time and reduces the incidence and spread of decay in storage.

The storage life of onions and garlic is extended by exposure to warm dry conditions for several days to dry the outside akin and prevent the ingress of spoilage organisms. This process is also known as curing although physiologically it is rather different and causes about 5% weight loss. Curing is carried out in the field when weather conditions are suitable; otherwise the product is subjected to forced circulation of warm dry air when first put into storage.

3.9 Genetic control of shelf life

Each variety of a horticultural crop has a limited storage life even under optimum storage conditions. The potential storage life is partly under genetic control and can be manipulated by breeding This very wide range of storage life is typical of horticultural products; each variety has its own particular life span.

Plant breeders should be encouraged to include potential storage life as one criterion in their programme for breeding improved varieties of roots, tubers, fruits and vegetables. This is particularly needed with the breeding programmes in tropical climates where refrigerated storage capacity is in short supply. This should be a high priority method for reducing losses in horticultural products.

Farmers should be encouraged to grow varieties that hare long storage life. Extension agents and experiment stations should be encouraged to include inherent storage life as one of the considerations to be taken into account when deciding which types of crops and which varieties of those crops should be recommended to farmers.

3.10 Shorten the time between harvest and consumption

In developing countries a considerable amount of produce is wasted because of poor transportation systems and poor marketing procedures. Much produce is spoiled because it is stored beyond its inherent shelf life before marketing is completed.

Improving transportation and marketing facilities, spreading the harvest season by growing varieties that mature at different times, and staggering the planting dates of annuals and reducing the number of steps between producer and consumer are methods that can be used to shorten the time between harvest and consumption.

3.11 Processing

Considerable quantities of fruit and vegetables are processed by dehydration, canning and freezing in developed countries. In developing countries small amounts of these commodities are processed for local consumption although large volumes of some commodities are processed for export (e.g., canned pineapple).

Canning and freezing require a high capital cost, high energy costs and expensive packaging and are unsuited for widespread use in less developed countries. Dehydration or sun drying is the simplest and lowest cost method of preservation and should be more widely used in developing countries because it converts a perishable commodity into a stable item with long storage life. Some excellent quality dehydrated products can be made from roots and tubers; this kind of processing should be encouraged.

3.12 Heat treatment

Some of the organisms that cause rotting are inhibited or killed at elevated temperatures that are below the injury threshold of the product. For example, hot water dipping of mangoes at about 50°C for a few minutes kills many pathogens without adversely affecting the quality of mango. Heat treatment is however not a desirable procedure for most fruits and vegetables. When applicable, very rigid temperature controls are needed.

3.13 Sanitation

All handling, storage, cleaning and washing equipment for horticultural products should be kept in a sanitary condition in order to minimize the risk of spreading infection. Diseased or damaged units should be sorted out and properly disposed off because their presence promotes the growth of fungi and bacteria. Insects infesting cull piles may fly to good produce and introduce pathogenic organisms and increase losses. Wash water should be changed at regular intervals before it becomes heavily contaminated with fungi and bacteria and spreads infection. In some cases the wash water is treated with chlorine or some other chemical in order to reduce the count of viable organisms.

3.14 Use of chemicals

A number of chemicals may be applied to horticultural products in order to obtain a desirable post-harvest effect. Most of these are applied after harvest, but a few are applied in the field in order to obtain a specific post-harvest response. For example, the sprouting of onions in storage can be delayed by spraying the onions with maleic hydrazide (MH) in the field while the tops are still green. Chemicals used pre harvest whose sole propose is to achieve a post-harvest effect should be included in the list of post-harvest chemical treatments.

Post-harvest chemicals are classified into groups. Many of these are not used commercially and are of research interest only:

a. Fungicides which prevent or delay the appearance of rot and molds in the product. Examples are, sodium orthophenylphenate (SOPP), benomyl, thiabendazole (TBZ), sodium hypochlorite, and sulphur dioxide (SO_2). Methyl formate (Erinol), ethyl formate and (in some countries) ethylene oxide are frequently applied to dried fruits to kill infestations of insects and molds. Sulphur dioxide and benzoic acid are frequently, and propionic acid, ascorbic acid or sorbic acid sometimes, added to processed fruit products, especially juices, to inhibit the growth of yeasts and molds.
b. Chemicals that delay ripening or senescence. Examples are: the kinins and kinetins that delay chlorophyll degradation and senescence in leafy vegetables, gibberellins that retard the ripening of tomatoes and hold citrus fruits on the tree beyond normal maturity, and auxins that delay physiochemical deterioration of oranges and green beans.

c. Growth retardants that inhibit sprouting and growth. Examples are maleic hydrazide which is applied pre-harvest and inhibits sprouting in a number of stored commodities, e.g., onions and potatoes. A number of chemicals are applied post-harvest to potatoes to control sprouting, for example, CIPC, TCNB and MENA. Daminozide (Alar) give a increased fruit firmness, bettor colour and early maturation in apples.
d. Chemicals that hasten ripening and senescence. Examples are ethylene and compounds such as Ephephon that release ethylene, abscisin, ascorbic acid, ß hydroxyethyl hydrazine (BOH), acetylene and substances that release acetylene such as calcium carbide, and certain alcohols and fatty acids.
e. Chemicals that may hasten or delay ripening and senescence depending on the dose and the commodity on which they are used. Examples are 2, 4-D; 2, 4, 5-T; indoleacetic acid (IAA) and naphthalene acetic acid (NAA).
f. Metabolic inhibitors that block certain biochemical reactions that normally occur. Examples are cycloheximide, actinomycin D, vitamin K, maleic acid, ethylene oxide, and carbon monoxide.
g. Ethylene absorbants. These delay ripening and senescence because they remove the ethylene produced by the fruit. They are usually placed in close proximity to the commodity and leave no residue on it. An example is potassium permanganate-impregnated alumina or vermiculite (fur fir).
h. Fumigants to control insects or sometimes molds. Ethylene dibromide and methyl bromide are the most commonly used fumigants.
i. Colouring. The use of artificial colours is sometimes permitted in order to improve the appearance of a fruit. For example, fresh grange from Florida (in USA) may have artificial colour added to the akin for cosmetic purposes. Since most people do not eat orange skins other than for marmalade it is considered to be a harmless addition.
   In warm climates ethylene is used to degreen lemons, oranges and tangerines imparting a brighter colour to the skin. Ethylene is a naturally occurring metabolite of ripening fruits.
j. Food additives. A number of compounds are permitted to be added to processed horticultural products for preservative or functional effect. The major preservatives are sulphur dioxide, benzoic acid or benzoates, and sorbic acid or sorbates. Functional additives include antioxidants, colouring, flavouring, thickeners, emulsifiers, etc. The use of food additives in the U.S.A. is regulated by the Food and Drug Administration

(FDA). Other countries have an equivalent government agency to regulate the use of additives. At the international level the Joint FAO/WHO Expert Committee on Food Additives (JECFA) formulates general principles governing the use of food additives and makes recommendations regarding their examination and control. Food additives will not be discussed further because they are only used in processing and formulating horticultural product a and are not applied to raw horticultural products. One exception is sulphur dioxide which is used to fumigate fresh grapes in cold storage in order to control growth of yeasts and molds.

There are two important differences between the use of chemicals in the field and the use of post-harvest chemicals:

i. Smaller quantities of post-harvest chemicals are used. For example, the normal dose of CIPC for controlling sprouting of potatoes is about 30 grams per ton and the normal dose of ethylene dibromide for fumigation of fruit a and vegetables is about 30 grams per ton. These levels contrast with the use of field chemicals where doses of one to several kg. per hectare are commonly used.
ii. The chemicals are not broadcast over the field but are applied in the confined apace of the storage chamber.

3.15 Pests

The major causes of lose in perishable produce after harvest are certain pathogenic fungi and bacteria. Viruses and nematodes play a minor role in postharvest losses; rodents and insects are also generally of lesser importance in contrast to the significant damage they cause in food grains.

In addition to the direct loss in quantity of food resulting from microbial infections, a partial loss results because of effect on appearance and/or quality resulting from disfiguring surface infections of fruit, root, and tuber crops. Other secondary adverse effects may include a decline in shelf life, possible contamination with mycotoxins, acceleration of ripening because of release of ethylene in pathogenesis by certain fungi, and in some instances deterioration of canned fruit crops because of the presence of heat-resistant hydrolytic enzymes formed by decay fungi in fruit tissues prior to the canning process.

The loss in the post-harvest period may originate from infections that were initiated by fungi during the growing season well in advance of harvest. Much of this pre-harvest infection involves a group of fungi that are capable of infecting healthy developing fruits either by direct penetration, e.g., anthracnose diseases caused by species of colletctrichum or by invasion via natural openings much as lenticels or stomata's or through breaks in the tissue at the points of attachment of fruits to the plant. In many cases the infection process may be incomplete. Thus, sub-cuticular mycelium may be formed which remains in a latent stage until the post-harvest period when changes in susceptibility may occur and the pathogen mycelium may ramify through the tissue.

Many of the fungi (e.g., species of Penicillium, Rhizopus, and Gectrichum) and bacteria (e.g., species of Erwinia, Bacillus and sometimes Clostridium) involved in decay problems associated with the post-harvest period may be considered as opportunistic pathogens. They are usually incapable of penetrating uninjured tissue or aggressively attacking vigorous healthy plants during their active growth period. However, they do have the ability to parasites fleshy plant organs when tissues are bruised, injured by insects, or otherwise placed under environmental stress. In many cases tissues are invaded by a succession of organisms which may interact in a synergistic manner.

Each species of root, tuber or fruit is affected by specific groups of fungal or bacterial pathogens. It is important that broad non-specific designations of these organisms be avoided (i.e., molds or rot organisms). The species of fungi or bacteria associated with specific decay problems should be properly identified. For example, it has been clearly shown that species of Knisopus differ markedly in their susceptibility to specific fungicides.

7.0 Conclusion

In this unit we have treated technologies of reducing post harvest losses such as gentle handling, temperature management, humidity control, field factors, suberization, genetic control of shelf life, shortening the time between harvest and consumption, waxing processing, heat treatment, use of chemical, sanitation and pest control.

5.0 Summary

The basic methods of control involve three different approaches 1) prevention of infection 2) elimination of incipient or latent infections, and 3) prevention of spread of the pathogen in the host tissue. Losses due to micro-organisms may be reduced by, refrigeration, improved handling procedures and pre- and post-harvest chemical control. Although every effort needs to be made to minimize or reduce dependence on chemicals, in many cases no viable alternatives exist. A wide range of fungicides are now available that are effective and safe to use. Incipient infections can be eliminated or reduced by application of certain fungicides such as benomyl which have the capacity of diffusing into host tissue and killing the pathogen in situ. Certain fungal pathogens initiate infections of fruits and vegetables during the growing season and these can be controlled best by timely application of fungicides prior to harvest. It is essential to ensure that chemical controls are used properly.

6.0 Tutor Marked Assignment (TMA)

1. State the basic principles which must be correctly applied for successful refrigeration of perishable crops
2. Describe the two important differences between the use of chemicals in the field and the use of post-harvest chemicals:
3. Explain the role of pest and diseases in causing crop loss and state measures to control them
4. Describe Suberization and curing of root and tuber crops
5. Describe the procedures for temperature and humidity control
6. Describe Technology of Reducing Post harvest losses by pest control

7.0 References and Further Readings

1. A.A. Kader (ed). Postharvest technology of horticultural crops, third edition. University of California , ANR Publication 3311.
2. Adaskaveg, J.E., H. Forster, and N.F. Sommer. 2002. Principles of postharvest pathology and management of decays of edible horticultural crops. p. 196-195,
3. Batten, D. J. and Loebel, M. R. (1984). Agfacts: Lychee harvesting and post-harvest handling. New South Wales Department of Agriculture, Australia.
4. Batten, D. J. (1989) Maturity criteria for litchis (lychees). *Food Quality Preference* **1**, 149-55
5. Diane M. Barrett; (2000) processing of horticultural crops No. 37 pg.466-479
6. **D.L. Proctor**, (1994) **Grain storage techniques** Evolution and trends in developing countries **FAO AGRICULTURAL SERVICES BULLETIN No. 109**
7. D.W. Hall, (1969)"Food Storage in Developing Countries," J.R. Soc. Arts, 142: 562-579 (1969)
8. Harris, Kenton L. and Carl J. Lindblad, eds. (1976) Postharvest Grain Loss Assessment Methods - A Manual of Methods for the Evaluation of Postharvest Losses American Association of Cereals Chemists, 1976
9. Jelle Hayma. (2003) The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
10. Lisa Kitinoja and Adel A. Kader (2002) Small Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th edition). July 2002
11. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.

12. MISSING FOOD: (2011).The Case of Postharvest Grain Losses in Sub-Saharan Africa. World Bank Report No. 60371-AFR
13. O. Charles Aworh (2008); The Role of Traditional Food Processing Technologies In National Development: the West African Experience. International Union of Food Science & Technology (2008)
14. Post-harvest Food Losses in Developing Countries (National Academy of Sciences, Washington, D.C., USA, 1978).
15. Thompson, J.F. and Spinoglio, M. (1994). Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
16. Schulten . G. G. M (2002) Post-harvest losses in tropical Africa and their prevention Royal Tropical Institute, Amsterdam, Netherlands
17. http://www.fao.org/docrep
18. http://postharvest.ucdavis.edu
19. http://www.crcpress.com/product
20. http://www.actahort.org/books
21. http://sciencedirect.com/science/journal
22. http://www.stewartspostharvest.com

UNIT 4 POST-HARVEST TREATMENTS TO MINIMIZE PRODUCE CONTAMINATION AND TO MAXIMIZE QUALITY

Table of Contents

3.2. 1 Field curing

3.3 Operations prior to packaging

3.4 Packhouse operations

3.5. Recent trends in handling perishable

- **3.5.1 Selection of cultivars**
- **3.5.2 Packing and packaging**
- **3.5.3 Cooling and storage**
- **3.5.4 Post harvest Integrated pest management**
- **3.5.5 Transportation**
- **3.5.6 Handling at wholesale and retail market**
- **3.5.7 Food Safety Assurance**

4.0Conclusion

5.0 Summary

6.0 Tutor Marked Assignment (TMA)

6.0References and Further Reading

1.0 Introduction

When roots, tubers, fruits and vegetables are to be stored for long periods, certain post harvest treatments are necessary to maintain quality and extend the shelf life. The curing process involves the application of high temperatures and high relative humidity to the roots and tubers for long periods, in order to heal the skins wounded during harvesting. Certain preliminary treatments designed to improve appearance and maintain quality include cleaning, disinfection, while sorting, grading and packing are often carried out in a packhouse. The marketable life of most fresh vegetables, tubers, roots and bulbs can be extended by prompt storage in an environment that maintains product quality. The desired environment can be obtained in facilities where temperature, air circulation, relative humidity, and sometimes atmosphere composition can be controlled. The first line of defense against insects and disease is good management during production. Planting resistant varieties, the use of irrigation practices that do not wet the leaves or flowers of plants, avoiding over-fertilization with nitrogen, and pruning during production to reduce canopy overgrowth can all serve to reduce produce decay before and after harvest. A second important defense is careful harvesting and preparation for market in the field. Thirdly, sorting out damaged or decaying produce will limit contamination of the remaining, healthy produce. Yet, even when the greatest care is taken, sometimes produce must be treated to control insects or decay-causing organisms.

2.0 Objectives

By the end of this unit you would be able to

i. identify post harvest handling practices for root, tubers and bulb crops
ii. describe the post harvest treatments to avoid microbial contamination
iii. describe the operations prior to packaging
iv. describe storage practices for roots, tubers and bulb crops
v. describe pest and decay control practices that ensures quality of produce

3.1 Post-Harvest Treatments to Minimize Produce Contamination and to Maximize Quality

3.1.1 Reduction of Microbial Contamination

Over the past few years, food safety has become and continues to be the number one concern of the fresh produce industry. A "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables," was published by the U.S. Food and Drug Administration in October 1998. This guide is based on the following principles:

(1) Prevention of microbial contamination of fresh produce is favored over reliance on corrective actions once contamination has occurred;

(2) In order to minimize microbial food safety hazards in fresh produce, growers, packers, or shippers should use good agricultural and management practices in those areas over which they have control;

(3) Fresh produce can become microbiologically contaminated at any point along the farm-to-table food chain. Human and/or animal faeces are the source of microbial contamination of fresh produce;

(4) Whenever water comes in contact with produce, its quality dictates the potential for contamination. The potential of microbial contamination from water used with fresh fruits and vegetables must be minimized;

(5) The use of animal manure or municipal biosolid wastes as fertilizers should be closely managed in order to minimize the potential for microbial contamination of fresh produce; and

(6) Worker hygiene and sanitation practices during production, harvest, sorting, packing, and transport play a critical role in minimizing the potential for microbial contamination of fresh produce."

A training manual for trainers, entitled "Improving the Safety and Quality of Fresh Fruits and Vegetables," was published by the United States Food and Drug Administration (USFDA) in November 2002, with the objective of providing uniform, broad-based scientific and practical information on the safe production, handling, storage, and transport of fresh produce.

Clean water containing an appropriate concentration of sanitizers is required in order to minimize the potential transmission of pathogens from water to produce, from healthy to infected produce within a single lot, and from one lot of produce to another, over time. Waterborne microorganisms, including post-harvest plant pathogens and agents of human illness, can be rapidly acquired and taken up on plant surfaces. Natural plant surface contours, natural openings, harvest and trimming wounds and scuffing can provide points of entry as well as safe harbor for microbes. When located in these protected sites, microbes are largely unaffected by common or permitted doses of post-harvest water sanitizing treatments It is therefore essential that the sanitizer concentration is sufficient to kill microbes before they attach or become internalized in produce. The concentration of sanitizer is important in some pre-harvest water uses (such as spraying pesticides or growth regulators) and in all post-harvest procedures involving water, including washing, cooling, water-mediated transport (flumes), and post-harvest drenching with calcium chloride or other chemicals.

3.1.2 Minimizing water loss

Transpiration, or evaporation of water from the plant tissues, is one of the major causes of deterioration in fresh horticultural crops after harvest. Water loss through transpiration not only results in direct quantitative losses (loss of saleable weight), but also causes losses in appearance (wilting, shriveling), textural quality (softening, flaccidity, limpness, loss of crispness and juiciness), and nutritional quality. Transpiration can be controlled either through the direct application of post-harvest treatments to the produce (surface coatings and other moisture barriers) or through manipulation of the environment (maintenance of high relative humidity).

Treatments that can be applied to minimize water loss in fruits and vegetables include:

a. Curing of certain root vegetables, such as garlic, onion, potato, and sweet potato.

b. Waxing and the use of other surface coatings on commodities, such as apple, citrus fruits, nectarine, peach, plum, pomegranate, and tomato.

c. Packaging in polymeric films that act as moisture barriers.

d. Careful handling to avoid physical injuries, which increase water loss from produce.

e. Addition of water to those commodities that tolerate misting with water, such as leafy vegetables

3.1.3 Reduction of ethylene damage

The promotion of senescence in harvested horticultural crops by ethylene (1 ppm or higher) results in acceleration of deterioration and reduced post-harvest life. Ethylene accelerates chlorophyll degradation and induces yellowing of green tissues, thus reducing the quality of leafy, floral, and immature fruit-vegetables and foliage ornamentals. Ethylene induces abscission of leaves and flowers, softening of fruits, and several physiological disorders. Ethylene may increase decay development of some fruits by accelerating their senescence and softening and by inhibiting the formation of antifungal compounds in the host tissue. In some cases, ethylene may stimulate the growth of fungi, such as *Botrytis cineria* on strawberries and *Penicillium italicum* on oranges.

The incidence and severity of ethylene-induced deterioration symptoms is dependent upon temperature, time of exposure, and ethylene concentration. The yellowing of cucumbers can, for example, result from exposure to either 1 ppm ethylene over 2 days or to 5 ppm ethylene over 1/2 day at 10 °C. Ethylene effects are cumulative throughout the post-harvest life of the commodity.

Treatment of ornamental crops with 1-methylcylopropene (1-MCP), which is an ethylene action inhibitor, provides protection against ethylene damage. The commercial use of this product at concentrations of up to 1 ppm on apples, apricots, avocados, kiwifruit, mangoes, nectarines, papayas, peaches, pears, persimmons, plums, and tomatoes was approved by the United States Environmental Protection Agency. The use of 1-MCP will no doubt be extended to several other fruits and vegetables, and to use in other regions.

3.1.4 Decay control

A major cause of losses in perishable crops is the action of a number of microorganisms on the commodity. Fungi and bacteria may infect the plant organ at any time. "Latent" infections, in which fungi invade fruit tissues shortly after flowering, become apparent only at the onset of ripening. Post-harvest rots frequently occur as a result of rough handling during the marketing process and are caused by a wide array of microorganisms. The grey mold *Botrytis cineria* is a very important cause of loss in many commodities (such as grapes, kiwifruit, pomegranates, raspberries, and strawberries), and is an aggressive pathogen, even at low temperatures. Virus infection frequently lowers the quality of perishable commodities, usually as a result of visual deterioration, although viruses may also affect flavor and composition.

Sanitation practices include treatment to reduce populations of microorganisms on equipment, on the commodity, and in the wash water used to clean it. Water washes alone are effective in removing nutrients that allow microorganisms to grow on the surfaces of produce as well as in removing inoculum of post-harvest pathogens. The addition of sanitizers to water dumps and spray or dip washes, reduces inoculum levels of decay-causing organisms from fruit surfaces, inactivates spores brought into solution from fruit or soil and prevents the secondary spread of inoculum in water.

Treatments for decay control include:

- heat treatments, such as dipping mangoes in water at a temperature of 50 °C, for 5 minutes in order to reduce subsequent development of anthracnose; (2)
- use of post-harvest fungicides, such as imazalil and/or thiabendazole on citrus fruits;
- (3) use of biological control agents, such as "Bio-Save" (*Pseudomonas syringae*) and "Aspire" (*Candida oleophila*) alone or in combination with fungicides at lower concentrations on citrus fruits;
- (4) use of growth regulators such as gibberellic acid or 2, 4-D to delay senescence of citrus fruits; (5) use of 15-20 percent CO_2 in air or 5 percent O_2 on strawberries, cane berries, figs, and pomegranates; and (6) use of SO_2 fumigation (100 ppm for one hour) on grapes. strawberries, cane berries, figs, and pomegranates; and
- (6) use of SO_2 fumigation (100 ppm for one hour) on grapes.

Biological control and plant growth regulators

Two biological control products (antagonistic organisms) are currently used as complementary tools (to chemical and/or heat treatments) for the management of postharvest decays together with other strategies as part of an integrated pest management program for a few fruits and vegetables (see table below).

Two plant growth regulators can be used to delay senescence of citrus fruits and consequently delay their susceptibility to decay (see table below).

TABLE 1.2.3 Commercially available biological control materials and plant growth regulators (PGR) registered as postharvest treatments:

Category	Organism/ Product	Year introduced	Crop	Decay organisms or function	Methods of application	Residue tolerance (ppm)
Biocontrol	*Pseudomonas syringae* Bio-Save)	1995	Citrus	*Penicillium digitatus,* *P. italicum,* *Geotrichum citri- aurantii*	Dip or spray	exempt
			Cherries	*Penicillium expansum,* *Botrytis cinerea*	Drench	exempt
			Apples,	*Penicillium expansum,* *Botrytis cinerea,*	Dip or	exempt

			pears	*Mucor piriformis*	drench	
			Potatoes	*Fusarium sambucinum, Helminthosporium solani*	Dip or spray	exempt
Biocontrol	*Candida oleophila (Aspire)*	1995	Pome fruits	Decay pathogens	Any type of application	exempt
			Citrus	Decay pathogens	Any type of application	exempt
PGR	Gibberellic acid (Pro Gibb)	1955	Citrus	Delays senescence (delays onset of decay)	Storage wax	exempt
PGR	2,4-D (Citrus Fix)	1942	Citrus	Delays senescence of buttons (delays onset of decay)	Storage wax	5

Sources: Adaskaveg, J.E., H. Forster, and N.F. Sommer. 2002. Principles of postharvest pathology and management of decays of edible horticultural crops. p. 196-195, in: A.A. Kader (ed). Postharvest technology of horticultural crops, third edition. University of California , ANR Publication 3311.

3.1.5 Insect pest control

Fresh fruits, vegetables and flowers may harbor a large number of insects during post-harvest handling. Many of these insect species, in particular fruit flies of the family Tephritidae (e.g. Mediterranean fruit fly, Oriental fruit fly, Mexican fruit fly, Caribbean fruit fly), can seriously disrupt trade among countries. The identification and application of acceptable disinfestation treatments including irradiation will greatly facilitate globalization of trade in fresh produce. Criteria for the selection of the most appropriate disinfestation treatment for a specific commodity include cost, the efficacy of that treatment against insects of concern, safety of the treatment as well as the ability of that treatment to preserve and maintain produce quality. Currently approved quarantine treatments, other than irradiation, include certification of insect-free areas, use of chemicals (e.g. methyl bromide, phosphine, hydrogen cyanide), cold treatments, heat treatments, and combinations of these treatments, such as methyl bromide fumigation in conjunction with cold treatment. The use of alternative treatments, such as fumigants (carbonyl sulphide, methyl iodide, sulphuryl fluoride) and insecticidal atmospheres (oxygen concentrations of less than 0.5 percent and/or carbon dioxide concentrations ranging between 40 and 60 percent) alone or in combination with heat treatments, and ultraviolet radiation, are currently under investigation. These treatments are not, however, broad-spectrum treatments and are potentially phytotoxic when applied to some commodities.

The first line of defense against insects and disease is good management during production. Planting resistant varieties, the use of irrigation practices that do not wet the leaves or flowers of plants, avoiding over-fertilization with nitrogen, and pruning during production to reduce canopy overgrowth can all serve to reduce produce decay before and after harvest. A second important defense is careful harvesting and preparation for market in the field. Thirdly, sorting out damaged or decaying produce will limit contamination of the remaining, healthy produce. Yet, even when the greatest care is taken, sometimes produce must be treated to control insects or decay-causing organisms.

Most insects become sterile when subjected to irradiation doses ranging between 50 and 750 Gy. The actual dosage required to produce sterility in insects varies in accordance with the species concerned and its stage of development. An irradiation dose of 250 Gy was approved by the United States quarantine authorities for application to fresh commodities, such as lychees, mangoes, and papayas in light of the efficacy of that dose in preventing the reproduction of tropical fruit flies. Irradiation doses of 250 Gy can be tolerated by most fresh fruits and vegetables with minimal detrimental effects on quality. Doses ranging between 250 and 1000 Gy (the maximum irradiation dose allowed as of 2002), can, however, be damaging to some commodities. Fruits, in general, are more tolerant to the expected dose range (250 to 500 Gy absorbed by fruits on the inside vs. those on the outside of the pallet) than non-fruit vegetables and cut flowers. Detrimental effects of irradiation on fresh produce may include loss of green color (yellowing), abscission of leaves and petals, tissue discoloration, and uneven ripening. These detrimental effects may not become visible until after the commodity reaches the market. The effects of irradiation must therefore be tested on individual commodities, prior to large-scale commercialization of the irradiation treatment.

While high humidity in the storage environment is important for maintenance of high quality produce, any free water on the surface of commodities can enhance germination and penetration by pathogens. When cold commodities are removed from storage and left at higher ambient temperatures, moisture from the surrounding warm air condenses on the colder product's surfaces. A temporary increase in ventilation rate (using a fan) or increasing exposure of the commodity to drier air can help to evaporate the condensed moisture and to reduce the chances of infection.

Hot water treatment: Crops may be immersed in hot water before storage or marketing to control disease. A common disease of fruits known as anthracnose, caused by the infection of fungus *Colletotrychum spp*. can be successfully controlled in this way. Combining appropriate doses of fungicides with hot water is often effective in controlling disease in fruits after harvesting. Hot water dips or heated air can be used for direct control of postharvest insects. In mangoes, an effective treatment is 46.4 °C for 65 to 90 minutes, depending on fruit size, variety and country of origin (Mitcham et al in Kader, 2002). Fruit should not be handled immediately after heat treatment. Whenever heat is used with fresh produce, cool water showers or forced cold air should be provided to help return the fruits to their optimum temperature as soon as possible after completion of the treatment.

Some pathogens are susceptible to heat treatments. Brief hot water dips or forced-air heating can be effective for disease control, especially for reducing the microbial load for crops such as plums, peaches, papaya, cantaloupe and stone fruits (Shewfelt, 1986), sweetpotatoes and tomatoes.

Table 1.2.3. Hot water treatments

Commodity	Pathogens	Temperature (C)	Time (min)	Possible injuries
Apple	*Gloeosporium sp.* *Penicillium expansum*	45	10	Reduced storage life
Grapefruit	*Phytophthora citrophthora*	48	3	
Green Beans	*Pythium butleri* *Sclerotinia sclerotiorum*	52	0.5	
Lemon	*Penicillium digitatum* *Phytophthora sp.*	52	5-10	
Mango	Anthracnose *Collectotrichum gloeosporioides*	52	5	No stem rot control
Melon	Fungi	57-63	0.5	
Orange	*Diplodia sp*	53	5	Poor de-greening

	Phomopsis sp. *Phytophthora sp.*			
Papaya	Fungi	48	20	
Papaya*	Anthracnose *Colletotrichum gleosporioides*	42 49	30 20	
Peach	*Monolinia fruticola* *Rhizopus stolonifer*	52	2.5	Motile skin
Pepper (bell)	*Erwinia sp.*	53	1.5	Slight spotting

* papaya anthracnose control requires both treatments, 30 min at 42 C followed by 20 min at 49 C.

Table 3.2.3 Hot forced-air treatments

Commodity	Pathogens	Temperature (C)	Time (min)	RH (%)	Possible injuries
Apple	*Gloeosporium sp.* *Penicillium expansum*	45	15	100	Deterioration
Melon	Fungi	30-60	35	low	Marked breakdown
Peach	*Monolinia fruticola* *Rhizopus stolonifer*	54	15	80	
Strawberry	*Alternaria sp.* *Botrytis sp.,* *Rhizopus sp.* *Cladosporium sp.*	43	30	98	

Sources: Barkai-Golan, R. and Phillips, D.J. 1991. Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.

Freezing: Control of storage insects in nuts and dried fruits and vegetables can be achieved by freezing, cold storage (less than 5°C or 41°F), heat treatments, or the exclusion of oxygen (0.5% or lower) using nitrogen. Packaging in insect-proof containers is needed to prevent subsequent insect infestation

Some plant materials are useful as natural pesticides. Cassava leaves are known to protect harvested cassava roots from pests when used as packing material in boxes or bags during transport and short-term storage. It is thought that the leaves release cyanogens, which are toxic to insect

Washing produce with chlorinated water can prevent decay caused by bacteria, mold and yeasts on the surface of produce. Calcium hypochlorite (powder) and sodium hypochlorite (liquid) are inexpensive and widely available.

Cold treatment: Certain fungi and bacteria in their germination phase are susceptible to cold, and infections can be reduced by treating produce with a few days of storage at the coldest temperature the commodity can withstand without incurring damage, and pathogen growth can be nearly stopped by storage at temperatures below 5 ° C (41 ° F).

Cold treatments can also serve to control some insect pests, and are currently allowed for the control of fruit flies, the false codling moth, melon fly, pecan weevil and lychee fruit borer. Treatment for control of fruit flies requires 10 days at 0 ° C (32 ° F) or below, or 14 days at 1.7 ° C (35 ° F) or below, so treatment is only suited to commodities capable of withstanding long-term low-temperature storage such as apples, pears, grapes, kiwifruit and persimmons.

3.2 Curing of Roots, Tubers, and Bulb crops

Curing is a post-harvest treatment that facilitates certain anatomical and physiological changes that can prolong the storage life of some root crops. It is one of the most effective and simple means of reducing water loss and decay during subsequent storage of root, tuber, and bulb crops, such as those listed in Table 4.2.3

When roots and tubers are to be stored for long periods, curing is necessary to extend the shelf life. The curing process involves the application of high temperatures and high relative humidity to the roots and tubers for long periods, in order to heal the skins wounded during harvesting. With this process a new protected layer of cells is formed. Initially the curing process is expensive, but in the long run, it is worthwhile.

Table **4.2.3** Conditions for curing roots and tubers.

Commodity	Temperature (°C)	Relative Humidity (%)	Storage time (days)
Potato	15-20	90-95	5-10
Sweet potato	30-32	85-90	4-7
Yams	32-40	90-100	1-4

Cassava	30-40	90-95	2-5

Source: FAO (1995a)

Curing can be accomplished in the field or in curing structures conditioned for that purpose. Commodities such as yams can be cured in the field by piling them in a partially shaded area. Cut grass or straw can serve as insulating material while covering the pile with canvas, burlap, or woven grass matting. This covering will provide sufficient heat to reach high temperatures and high relative humidity. The stack can be left in this state for up to four days.

3.2. 1 Field curing

Yams and other tropical root and tuber crops can be cured outdoors if piled in a partially shaded area. Cut grasses or straw can be used as insulating materials and the pile should be covered with canvas, burlap or woven grass mats. Curing requires high temperature and high relative humidity, and this covering will trap self-generated heat and moisture. The stack should be left for about four days.

Onions and garlic can be cured in the field in regions where harvest coincides with the dry season. The crops can be cured either in windrows or after packing into large fiber or net sacks. The produce can be left in the field for five days, then checked daily until the outer skin and neck tissues are properly dried. Curing may take up to ten days, depending on weather conditions.

Curing can be assisted by the use of ventilated sheds in regions where solar radiation and/or relative humidity is high or natural air movement is low. Produce in sacks can be stacked in the shade on canvas tarpaulins, or placed in an open sided shed under one or more ceiling fans. An exhaust vent in the roof can assist with air circulation.

3.3 Operations prior to packaging

Fruits, vegetables, root, tubers and bulbs are subjected to preliminary treatments designed to improve appearance and maintain quality. These preparatory treatments include cleaning, disinfection, waxing, and adding of colour (some includes brand name stamping on individual fruits).

i. Cleaning:

Most produce receives various chemical treatments such as spraying of insecticides and pesticides in the field. Most of these chemicals are poisonous to humans, even in small concentrations. Therefore, all traces of chemicals must be removed from produce before packing

ii. Disinfection:

After washing fruits and vegetables, disinfectant agents are added to the soaking tank to avoid propagation of diseases among consecutive batches of produce. In a soaking tank, a typical solution for citrus fruit includes a mixture of various chemicals at specific concentration, pH, and temperature, as well as detergents and water softeners. Sodium-ortho-phenyl-phenate (SOPP) is an effective citrus disinfectant, but requires precise control of conditions in the tank. Concentrations must be kept between 0.05 and 0.15%, with pH at 11.8 and temperature in the range of 43-48°C. Recommended soaking time is 3-5 minutes.

iii. Artificial waxing:

Artificial wax is applied to produce to replace the natural wax lost during washing of fruits or vegetables. This adds a bright sheen to the product. The function of artificial waxing of produce is summarized below:

- Provides a protective coating over entire surface.
- Seals small cracks and dents in the rind or skin.
- Seals off stem scars or base of petiole.
- Reduces moisture loss.
- Permits natural respiration.
- Extends shelf life.
- Enhances sales appeal.

3.4 Packhouse operations

Sorting, grading and packing are often carried out in a packhouse or shed, to protect workers and fruit from the elements. Where shelter is not available, operations are best located in a cool, shady area. Good hygiene in the packhouse is required to avoid the spread of diseases during handling. Pathogens can build-up on packing surfaces and fruit crates. These surfaces should be washed with sanitizing agents such as chlorine every day. Water and fungicide dips also require frequent replacement or sanitizing.

1. Sorting

Product quality is maintained by removing damaged and inferior fruit during sorting The entire surface of each fruit must be observed to ensure that damaged specimens are not packed. Immature fruit and fruit showing any signs of rot are also removed during sorting. Some markets have low tolerance for cosmetic defects, such as scale infestation, small fruit, severe pepper spot (anthracnose) infection or superficial browning. Fruit showing these defects are generally downgraded and not sent to the central markets, but can be processed or sold at roadside stalls.

2. Grading

Grading separates tubers into different grades to suit different markets. Most producers have at least two grades of fruit. Grading is normally carried out during or after sorting. Grading systems depend on market requirements, but are normally based on produce size and colour, and the area of blemish. Export markets usually have higher standards than domestic markets, requiring uniform, unblemished fruit. There can also be differences within different sections of the domestic market.

3. Fungicides

Post-harvest treatments with fungicides can slow rot development, but the required equipment and chemicals are expensive. Although several chemicals are effective, few have been registered for commercial use. There are also increasing concerns about residues in fruit.

4. Disinfestations

Some export markets require disinfestations of fruit for insect pests. There are several methods available to kill the insect, but fruit are often damaged in the process. There are also health concerns regarding treatments such as ethylene dibromide and gamma irradiation

5. Packing

Selection of packaging depends on market preferences and availability. The ideal package protects fruit from damage and minimizes water loss and condensation.

6. Transport

Poor transport conditions are a major problem in Africa. The main limitations, including rough roads, lack of refrigeration and poor truck suspension, are out of the control of growers. Fruit are often damaged when baskets are overfilled, dropped, stacked or packed on their sides. Shelves can be used in the truck to avoid stacking of baskets, and reduce damage to fruit. Padding and strapping the baskets can restrict movement during transport. Exposure to warm air can dry out the fruit very quickly, so transport during the warmer part of the day is best avoided, if possible. Fruit can be protected by covering the baskets with a clean tarpaulin or similar material.

3.5.Recent trends in Handling perishable produce

3.5.1 Selection of cultivars

For many commodities, producers are using cultivars with superior quality and /or long post harvest life, long shelf life tomatoes, super sweet sweet corn, sweeter melons etc. Plant geneticists in public and private institutions are using molecular biology methods along with plant breeding procedures to produce new genotypes that taste better, maintain firmness better, are more is disease resistant, have less browning potential and have other desirable characteristics.

3.5.2 Packing and packaging

The produce industry is increasingly using plastic containers that can be reused and recycled in order to reduce waste disposal problems. For example, stacking returnable plastic crates are becoming widely used. There is continued use of modified atmosphere and controlled atmosphere [packaging (MAP and CAP) system at the pallet, shipping container (fibreboard box liner), and consumer package levels. In addition, the use of absorbers of C_2H_4, CO_2, O_2 and /or water vapour as part of MAP and CAP is increasing.

3.5.3 Cooling and storage

The current trend is towards increased precision in temperature and relative humidity management to provide the optimal environment for fresh fruits and vegetables during cooling and storage. Forced air cooling continuous to be the predominant cooling method for horticultural perishables.

3.5.4 Post harvest Integrated pest management

Biological control agents are being used alone or in combination with reduced concentration of post harvest fungicides, heat treatments, and/or fungistatic CA for control of post harvest diseases. Chemical fumigants especially methyl bromide is still the primary method sued for insect control in harvested fruits when such treatment is required by quarantine authorities of importing countries. Many stiuides are underway to develop alternative methods of insect control that are effective and not phytotoxic to the fruits and present no health hazard to the consumer. These alternatives include cold treatments, hot water or air treatments, ionizing radiation and exposure to reduced (0.5%) O_2 or elevated CO_2 (40-60%) atmospheres. This is a high-priority research and development area because of the possible loss of methyl bromide as an option for insect control.

3.5.5 Transportation

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_4) 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 control centre, allowing all the shipments to be continuously monitored. Some new trucks have air ride suspension, which eliminate vibration damage. As the industry realizes the importance of air ride, its popularity will increase.

3.5.6 Handling at wholesale and retail market

Wholesale and retail markets have been increasingly using automated ripening in which the gas composition of the ripening atmosphere, the room temperature and the fruit colour are continuously monitored and modulated to meet desired ripening characteristics. Improved ripening systems will lead to greater use of ripening technology to deliver products that are ripened to the ideal eating stage. Better refrigerated display units, with improved temperature and RH monitoring and control systems are being used in the retail markets especially for fresh cut fruits and vegetables. Many retail and food service operators are using Hazard Analysis Critical Control Points (HACCP) programs to assure consumers that the food products are safe.

4.0 Conclusion

In this unit various post harvest practices such as Post Harvest Treatments to reduce microbial contamination, minimize water loss, to reduce ethylene damage, for decay control, to control of insects Pest, Curing of Roots, Tubers, and Bulb crops, Operations prior to packaging, Packhouse operations to maximize quality and prolong shelf life of crops were explained. The recent trends of handling perishable to ensure quality and prolong shelf life of produce was examined

5.0 Summary

Over the past few years, food safety has become and continues to be the number one concern of the fresh produce industry. Throughout the period between harvest and consumption, temperature control has been found to be the most important factor in maintaining product quality. Fruits, vegetables and cut flowers are living, respiring tissues separated from their parent plant. Keeping products at their lowest safe temperature (0 C or 32 F for temperate crops or 10-12 C or 50-54 F for chilling sensitive crops) will increase storage life by lowering respiration rate, decreasing sensitivity to ethylene gas and reducing water loss. Reducing the rate of water loss slows the rate of shriveling and wilting, causes of serious postharvest losses.

6. Tutor Marked Assignment (TMA)

i. discuss post harvest treatments to minimize loss and maximize quality of produce

ii. describe parkhouse operations to maximize quality of crop products

iii. describe treatments that can be applied to minimize water loss in fruits and vegetables
iv. Describe the treatments for decay control
v. Describe operations prior to packaging
vi. Describe the recent trends in handling perishable to ensure quality and prolong the shelf life of products

7.0References and Further Readings

1. .A.A. Kader (ed). Postharvest technology of horticultural crops, third edition. University of California , ANR Publication 3311.
2. Adaskaveg, J.E., H. Forster, and N.F. Sommer. 2002. Principles of postharvest pathology and management of decays of edible horticultural crops. p. 196-195,
3. Batten, D. J. and Loebel, M. R. (1984). Agfacts: Lychee harvesting and post-harvest handling. New South Wales Department of Agriculture, Australia.
4. Batten, D. J. (1989) Maturity criteria for litchis (lychees). *Food Quality Preference* **1**, 149-55
5. Diane M. Barrett; (2000) processing of horticultural crops No. 37 pg.466-479
6. **D.L. Proctor**, (1994) **Grain storage techniques** Evolution and trends in developing countries **FAO AGRICULTURAL SERVICES BULLETIN No. 109**
7. D.W. Hall, (1969)"Food Storage in Developing Countries," J.R. Soc. Arts, 142: 562-579 (1969)
8. Harris, Kenton L. and Carl J. Lindblad, eds. (1976) Postharvest Grain Loss Assessment Methods - A Manual of Methods for the Evaluation of Postharvest Losses American Association of Cereals Chemists, 1976
9. Jelle Hayma. (2003) The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
10. Lisa Kitinoja and Adel A. Kader (2002) Small Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th edition). July 2002

11. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
12. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa. World Bank Report No. 60371-AFR
13. O. Charles Aworh (2008); The Role of Traditional Food Processing Technologies In National Development: the West African Experience. International Union of Food Science & Technology (2008)
14. Post-harvest Food Losses in Developing Countries (National Academy of Sciences, Washington, D.C., USA, 1978).
15. Thompson, J.F. and Spinoglio, M. (1994). Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center, University of California, Davis.
16. Schulten . G. G. M (2002) Post-harvest losses in tropical Africa and their prevention Royal Tropical Institute, Amsterdam, Netherlands
17. http://www.fao.org/docrep
18. http://postharvest.ucdavis.edu
19. http://www.crcpress.com/product
20. http://www.actahort.org/books
21. http://sciencedirect.com/science/journal
22. http://www.stewartspostharvest.com

UNIT 5 CROP PRODUCT PROCESSING

Table of contents

3.3 Traditional food processing technology in West Africa

3.3.1 Traditional Fermentations

3.4 Challenges of crop processing

3.5 Future post-harvest research priorities

4.0 Conclusion

5.0 Summary

6.0 Tutor Marked Assignment

7.0References and Future Readings

1.0Introduction

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.

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 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 should be able to:

- Describe the basic principles of agricultural processing
- Describe the different types of agricultural processing
- Describe the method of processing cassava
- Describe the methods of processing cereals
- Describe the method of processing yam
- Process your farm produce successfully
- Describe traditional food processing technology in west Africa
- Discuss the challenges of crop processing
- Enumerate future post-harvest research priorities

3.0 Principles of agricultural processing

Food preservation may target to either the short or long term. Short term preservation may be applicable to horticultural commodities that are consumed relatively soon after harvest. For them the best preservation techniques involves keeping the product alive and respiring. Shorter preservation does not involve 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 encompasses inactivation or control of microorganisms and enzymes and reduction or elimination of chemical reactions that causes food deterioration. Microorganism 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. In a similar fashion, 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

3.1. 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 product which is suitable for food uses or consumption after cooking, roasting, frying etc.

Tertiary processing

Conversion of secondary processed material into ready to eat form.

Food items are marketed in different forms as raw, primary processed, secondary processed and tertiary processed. The farmers in general prefer to sell their agricultural produce immediately after harvest leaving a part for own 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.

3.1.2 Sector wise food processing

Food processing is the set of methods and techniques used to transform raw ingredients into food or to transform food into other forms for consumption by humans or animals either in the home or by the food processing industry. Food processing typically takes clean, harvested crops or slaughtered and butchered animal products and uses these to produce attractive, marketable and often long shelf-life food products. Similar processes are used to produce animal feed.

3.1.2.1 Fruits and vegetable processing

The processed products from fruits and vegetables are beverages, jams, jellies, candies, preserves, canned fruits and vegetables, dehydrated fruits and vegetables, pickles, soup mixes, sauces and ketchups. Processing of fruits and vegetables involves a series of processes which include precoloring washing, grading, treating, storage, dehydration, peeling, slicing, crushing, extraction, bleaching, sterilizing, filling, scaling and sealing of containers.

People generally prefer fresh fruits and vegetables in Nigeria due to abundance of seasonal fruits throughout the year available at low price. However, in the recent years, processed foods in the form of canned fruits such as pineapple, mango slices and pulps, grapes, apple, peaches etc have increased considerably. The uses of fruits in the form of concentrated juice, dry powder, jam and jelly have also increased.

3.1.1.2 Gari processing cottage industries that processed raw cassava in to garri

3.1.1.3 Rice milling: The modern rice mills have separate processing mechanism for dehusking and polishing of the paddy. The husk can be utilized for energy and for industrial products like furfural and the bran for extraction of edible and non edible grades oil. These mills also have better recovery and lower energy consumption compared to conventional hullers.

3.1.1.3 Wheat milling: At present flours made by the roller mills are sold to bakers and confectionery company etc Sale of soy blended and branded wheat flour is likely to increase due to better quality flour and thus scope of organized wheat milling will increase in future.

3.1.1.4 Pulse milling: Pulses are the major sources for protein for the vegetarians.

3.1.1.5 Oil extraction: Oil extraction has been a cottage level activity in the country through the numerous oil mills. The introduction of high capacity mechanical expellers and solvent extraction technology has brought in modernization. Small capacity oil expellers have been introduced which could be installed in rural areas for promoting agri - business and that might provide more employment. Soybean is not only a good source of oil but also rich in protein. Soymilk analogues, nuggets and soy - blends are now marketed

3.1.1.6 Processing of commercial crops

Sugarcane, rubber, cocoa, oil palm, tea and coffee are major commercial crops grown in Nigeria and a processed into variety of products

3.1.1.7 Packed and convenience food

Modern packed and convenience foods such as bread, biscuit, confectionery, chocolates, ready to eat foods like noodles, cereal flakes, etc have become popular in recent years especially in urban areas although traditional foods have been used in the country in the form of roasted, puffed, sweet meat and baked products.

3.2 Methods of processing crop produce

3.2.1Cereals

Flour milling is the continuous process that is used to transform the raw wheat berry into a form which is of use to the baking and other industries and the domestic consumer. A small portion of production is geared towards the production of whole-wheat flours, employing a simplified process flow sheet, but most demand and effort is directed towards the production of white flour.

White flour is the ultimate product of flour milling. The aim of white flour milling is to extract a maximum amount of endosperm from the wheat berry in as pure a form as possible. The outer bran layers become the co-product of the process called wheat feed. Many operations also separate the embryonic part of the berry, known as the germ. This is a high value co-product when a market exists. Where a market for germ does not exist, it is sold for animal feed with the wheat feed produced. These co-products contribute significantly to the financial viability of milling operations. One of the keys to the success of a flour milling operation is the efficient, economical separation of starchy endosperm from the rest of the berry. The process has developed along very specific lines towards achieving this goal.

There is just one accepted manner in which flour is produced globally. This is known as the gradual reduction system. The gradual reduction system of flour milling is the process of taking the whole wheat berry and, via a series of grinding and sieving stages, producing white flour of the desired quality and yield. The gradual reduction system has enabled the production of flours of low ash content and high yield. Specialist, high quality flours, is produced by extracting high purity sub-products from within the process. There are three principal divisions within the process. These are known as the breaking system, the purification system and the reduction system. The purification system is not favoured by many millers and may be absent from processes. It is often replaced by what is known as the Sizing system. However, the other two blocks are present in all gradual reduction flour mills in operation today. The breaking block or break system is the area of the process where most endosperm separation is achieved. This work is performed principally on roller mills whose surfaces have a saw tooth profile. The rollers run at different speeds towards each other.

3.2.2 Cassava

A great diversity of processing techniques has developed in different regions. Some of the processes are used in all areas either because they are standard methods for preparing starchy food, such as boiling or roasting or because they were introduced with the cassava when it was introduced from South America.

- The simplest techniques used to prepare cassava for immediate consumption are boiling, roasting or baking. Peeled roots are boiled whole or sliced and served in a variety of ways
- Roasting the roots is less popular with the Amerindians than boiling and generally only resorted to when no cooking utensils are available. Roots are roasted by placing them whole in the ashes of a fire
- Frying is believed not to have been used traditionally but to have been introduced by European. slices of peeled root are fried in oils of various kinds according to availability and taste
- In Vanuatu grated cassava is wrapped in banana leaves and baked in an oven

- The more complex technique involving pounding of the cassava roots into a paste is particularly popular on the African continent where it is a very widespread method, The resulting paste from all these crops is generally known in West Africa as fufu, also foofoo, fuifai, foufou, foutou and vou-vou depending on the locality.
- Fufu can be prepared by boiling or steaming peeled cassava roots and then pounding them in a wooden pestle and mortar until a homogeneous paste is obtained which is eaten with soups or stews of meat or fish
- The simplest method used and probably the most widespread certainly in Africa or Asia, for preparing flour from cassava is by sun-drying slices or chips of peeled roots which can then be stored as dried chips and ground into a flour when needed
- A method for extending the storage life of chips to up to 12 months and also speeding up the drying process is by parboiling them before drying, a technique often used in India and West Africa
- Amongst the most important products from Cassava roots are the coarse meals known as gari in West Africa

3.2.3 Yam

Yam, possibly the oldest cultivated food plant in West Africa, is of major importance to the economy of the sub-region that accounts for the bulk of world production of the crop. By far the most important product derived from white yam (*Dioscorea rotundata* Poir) **is fufu or pounded yam**, popular throughout West Africa. Traditionally, pounded yam is prepared by boiling peeled yam pieces and pounding using a wooden mortar and pestle until a somewhat glutinous dough is obtained.

Production of Instant Yam Flour

Arising from the need to have a convenience food and reduce the drudgery associated with the preparation of pounded yam, various brands of instant yam flour are now available in West Africa since the introduction of "poundo yam", which is no longer in the market, by Cadbury Nigeria Ltd in the 1970s. Instant yam, on addition of hot water and stirring, reconstitutes into a dough with smooth consistency similar to pounded yam. The product is so popular that considerable quantities are exported to other parts of the world, especially Europe and North America, where there are sizable African populations. Commonly, instant yam flour is produced by sulfiting peeled yam pieces, followed by steaming, drying, milling and packaging in polyethylene bags. Instant yam flour can also be produced by drum drying cooked, mashed yam and milling the resultant flakes into a powder using a process similar to that used for production of dehydrated mashed potato

3.2.4 Oil fruits

Since the oil palm gives the economically most important tropical oil fruit, the technologies for its extraction can serve as an example in this category.

In the traditional process, the fruit is first removed from the bunches, generally after the bunches have fermented for a few days. The fruit is then cooked and pounded or trampled. The mashed mass is mixed into water. The oil and oil containing cell material is separated from the fibre and the nuts by rinsing with excess water and pressing by hand. The oil-containing mass, now floating on the top, is collected and boiled. In this step, the oil separates from the rest and collects on the surface. It is skimmed off and finally dried.

The actual execution of the process may vary somewhat from area to area; most traditional processes, however, have in common the superfluous use of water. Using this process, generally not more than 50% of the oil is obtained. The problems are:

- the digestion by means of pounding or trampling,
- the separation of the oil and oil containing material from the fibres and the nuts by means of water and the liberation of the oil by cooking afterwards.

The potential for improvement of this technology and thereby the development of small scale extraction equipment in principal depends on

- better cooking by means of steam,
- better digesting using a reheating step with steam and
- more effective pressing in a batch press or continuously working screw press.

The modern process of extracting palm oil, used on a larger scale, starts with the steam sterilization of the bunches. The bunches are threshed and the fruit is digested mechanically, while heated with steam. The mass is then pressed in hydraulic presses or continuously in screw presses. The oil is separated from the press fluid by heating and is finally dried.

3.2.5 Oil seeds

In addition to the distinction made between traditional and modern methods, the processes for oil seeds should also be divided into so-called wet and dry extraction methods.

Of the traditional wet processes, the extraction of coconut oil from fresh coconuts is the best known. It starts with grating the meat, after which the oil as well as the proteins and impurities are extracted as milk from the fibrous residue by pressing (by hand or foot) and rinsing with fresh water. The milk is left to stand to form an oil rich cream on top. The cream is boiled to separate the oil from water and other impurities. The oil can be skimmed off. It still contains a protein- rich residue that can be filtered off after drying and used for human consumption.

Other oil seeds, like groundnuts, palmkernels and sheanuts are roasted and crushed as fine as possible (e.g. first by pounding, followed by crushing between stones or a stone and an iron bar). The crushed mass is mixed with water, and the oil is obtained by cooking the mixture, causing the oil to float. The oil is finally skimmed off and dried by heating. Sheanut oil is often obtained by beating air into a mixture of crushed seeds with some water using a hand-operated butter making process. The milk or cream floating on top of the beaten mass at the end of the process is then cooked to evaporate the water and dry the oil.

The weak points of these processes are the grating or crushing steps. They are time consuming and exhausting work, yet crushing is generally not fine enough. Thorough crushing can improve the oil recovery considerably. In many areas, engine-driven disc mills are used by women in small commercial enterprises to get their seed crushed.

3.3 Traditional food processing technology in West Africa

The capacity to preserve food is directly related to the level of technological development and the slow progress in upgrading traditional food processing and preservation techniques in

West Africa contributes to food and nutrition insecurity in the sub-region. Traditional technologies of food processing and preservation date back thousands of years and, unlike the electronics and other modern high technology industries, they long preceded any scientific understanding of their inherent nature and consequences. Traditional foods and traditional food processing techniques form part of the culture of the people. Traditional food processing activities constitute a vital body of indigenous knowledge handed down from parent to child over several generations. Unfortunately, this vital body of indigenous knowledge is often undervalued. Regrettably, some of the traditional food products and food processing practices of West Africa have undoubtedly been lost over the years and the subregion is the poorer for it. Those that the sub-region is fortunate to retain today have not only survived the test of time but are more appropriate to the level of technological development and the social and economic conditions of West African countries. Indeed, simple, low-cost, traditional food processing techniques are the bedrock of small-scale food processing enterprises in West Africa and their contributions to the economy are enormous. The objectives and main features of some of these traditional food processing techniques are presented in Table 1.5

Table 1.2.5 Objectives and main features of traditional West African food processing techniques

Technique/operations	objectives	Mean features/limitations
1. **Preliminary/postharvest operations:** threshing	To detach grain kernels from the panicle.	Carried out by trampling on the grain or beating it with sticks. Labor-intensive, inefficient, low capacity.
Winnowing	To separate the chaff from the grain.	Done by throwing the grain into the air. Labor intensive, low capacity, inefficient.
Dehulling	To remove the grain from its outer protective casing	Carried out by pounding the grain in amortar with pestle. Labor-intensive, low capacity excessive grain breakage.
Peeling	To separate the peel or skin from the edible	Manual peeling with knives or similar objects.

	pulp.	Labor-intensive, low capacity, loss of edible tissue.
2. Milling (e.g. corn)		
Dry milling	To separate the bran and germ from endosperm	Carried out by pounding in a mortar with pestle or grinding with stone. Laborious, inefficient, limited capacity.
Wet milling	To recover mainly starch in the production of fermented foods e.g. ogi.	Carried out by pounding or grinding after steeping. Laborious, limited capacity, high protein losses, poor quality product.
3. Heat processing		
Roasting	To impart desirable sensory qualities, enhance palatability, reduce anti-nutritional factors.	Peanuts are roasted by stirring in hot sand in a flat-bottom frying pot over a hot flame. Laborious, limited capacity.
Cooking (e.g. wara)	To contract curd and facilitate whey expulsion, reduce microbial load, inactivate vegetable rennet, impart desirable sensory qualities.	Loose curd pieces are cooked in a pot over wood fire. Limited capacity.
Parboiling (e.g. rice)	To facilitate milling and enrich milled rice with B-vitamins and minerals.	Done by steeping paddy rice in cold or warm water followed by steaming in bags in drums. Limited capacity, poor quality product.
Blanching	To inactivate plant enzymes and minimize oxidative changes leading to deterioration in sensory and nutritional qualities, e.g. enzymatic browning.	Slices (e.g. yam for elubo production) are heated in hot water in a pot for various durations. Limited capacity, poor quality product.

4. Drying		
Shallow layer sun drying	To reduce moisture content and extend shelf life.	Product is spread in a thin layer in the open (roadside, rooftop, packed earth etc.). Labor intensive, requires considerable space, moisture too high for long-term stability, poor quality.
Smoke drying (e.g. banda)	To impart desirable sensory qualities, reduce moisture content and extend shelf life.	Meat chunks after boiling are exposed to smoke in earthen kiln or drum. Limited capacity, poor quality product.
5. Fermentation	To extend shelf life, inhibit spoilage and pathogenic microorganisms, impart desirable sensory qualities, improve nutritional value or digestibility.	Natural fermentation with microbial flora selection by means of substrate composition and back-slopping. Limited capacity, variable quality.

Source: International Union of Food Science & Technology (2008)

3.3.1 Traditional Fermentation

Fermentation is one of the oldest and most important traditional food processing and preservation techniques. Food fermentations involve the use of microorganisms and enzymes for the production of foods with distinct quality attributes that are quite different from the original agricultural raw material. The conversion of cassava (*Manihot esculenta, Crantz* syn. *Manihot utilissima* Pohl) to gari illustrates the importance of traditional fermentations. Cassava is native to South America but was introduced to West Africa in the late 16th century where it is now an important staple in Nigeria, Ghana, Ivory Coast, Sierra Leone, Liberia, Guinea, Senegal and Cameroon. Nigeria is one of the leading producers of cassava in the world with an annual production of 35-40 million metric tons. Over 40 varieties of cassava are grown in Nigeria and cassava is the most important dietary staple in the country accounting for over 20% of all food crops consumed in Nigeria. Cassava tubers are rich in starch (20-30%) and, with the possible exception of sugar cane, cassava is considered the highest producer of carbohydrates among crop plants. Despite its vast potential, the presence of two cyanogenic glucosides, linamarin (accounting for 93%of the total content) and lotaustralin or methyl linamarin, that on hydrolysis by the enzyme linamarase release toxic HCN, is the most important problem limiting cassava utilization. Generally cassava contains 10-500 mg HCN/kg of root depending on the variety, although much higher levels, exceeding 1000 mg HCN/kg, may be present in unusual cases. Cassava varieties are frequently described as sweet or bitter. Sweet cassava varieties are low in cyanogens with most of the cyanogens present in the peels. Bitter cassava varieties are high in cyanogens that tend to be evenly distributed throughout the roots. Environmental (soil, moisture, temperature) and other factors also influence the cyanide content of cassava. Low rainfall or drought increases cyanide levels in cassava roots due to water stress on the plant. Apart from acute toxicity that may result in death, consumption of sub-lethal doses of cyanide from cassava products over long periods of time results in chronic cyanide toxicity that increases the prevalence of goiter and cretinism in iodine-deficient areas.

CASSAVA ROOTS

(306 mg HCN/kg)

↓

PEELING HCN

(184 mg HCN/kg)→ HCN

↓

WASHING

↓

GRATING

↓

FERMENTING

↓

PRESSING HCN

(52 mg HCN/kg) → HCN

↓

SIFTING

↓

ROASTING HCN → HCN

↓

SIEVING

↓

GARI

(10 mg HCN/kg)

Figure 1. Process flow chart for gari production show

Symptoms of cyanide poisoning from consumption of cassava with high levels of cyanogens include vomiting, stomach pains, dizziness, headache, weakness and diarrhea . Chronic cyanide toxicity is also associated with several pathological conditions including konzo, an irreversible paralysis of the legs reported in eastern, central and southern Africa, and tropical ataxic neuropathy, reported in West Africa, characterized by lesions of the skin, mucous membranes, optic and auditory nerves, spinal cord and peripheral nerves and other symptoms.

Without the benefits of modern science, a process for detoxifying cassava roots by converting potentially toxic roots into gari was developed, presumably empirically, in West Africa. The process involves fermenting cassava pulp from peeled, grated roots in cloth bags and after dewatering, the mash is sifted and fried.

During fermentation, endogenous linamarase present in cassava roots hydrolyze linamarin and lotaustralin releasing HCN. Crushing of the tubers exposes the cyanogens which are located in the cell vacuole to the enzyme which is located on the outer cell membrane, facilitating their hydrolysis. Most of the cyanide in cassava tubers is eliminated during the peeling, pressing and frying operations (Figure 1). Processing cassava roots into gari is the most effective traditional means of reducing cyanide content to a safe level by WHO standards of 10 ppm, and is more effective than heap fermentation and sun drying, commonly used in eastern and southern Africa. Apart from 'gari' there is a vast array of traditional fermented foods produced in Nigeria and other West African countries (Table 2.2.5). These include staple foods such as fufu, lafun and ogi; condiments such as iru (dawadawa), ogiri (ogili) and ugba (ukpaka); alcoholic beverages such as burukutu (pito or otika), shekete and agadagidi; and the traditional fermented milks and cheese. Lactic acid bacteria and yeasts are responsible for most of these fermentations. The fermentation processes for these products constitute a vital body of indigenous knowledge used for food preservation, acquired by observations and experience, and passed on from generation to generation.

Table 2.2.5 some traditional Nigerian fermented foods

Fermented food	Raw materials	Microorganism involved	Uses
Gari	Cassava pulp	*Leuconostoc* spp. *Lactobacillus* spp. *Streptococcus* spp. *Geotrichum candidum*	Main Meal
Fufu	Whole cassava roots	*Lactobacillus* spp. *Leuconostoc* spp.	Main meal
Lafun	Cassava chips	*Leuconostoc* spp. *Lactobacillus* spp. *Corynebacterium* spp. *Candida tropicalis*	Main meal
Ogi	Maize, sorghum and millet	*Lactobacillus plantarum* *Streptococcus lactis* *Saccharomyces cerevisiae* *Rodotorula* spp. *Candida mycoderma* *Debaryomyces hansenii*	Breakfast cereal, weaning food
Iru (Dawadawa)	African locust bean (*Parkia biglobosa)* Soya bean	*Bacillus subtilis* *B. licheniformis*	Condiment
Ogiri (Ogili)	Melon seed (*Citrullus vulgaris*), Fluted pumpkin (*Telfairia occidentalis*), Castor oil seed (*Ricinus communis*)	*Bacillus* spp. *Escherichia* spp. *Pediococcus* spp.	Condiment

Kpaye	*Prosopsis africana* (algarroba or mesquite	*Bacillus subtilis* *Bacillus licheniformis* *Bacillus pumilus*	Condiment
Ugba (Ukpaka)	African oil bean (*Pentaclethra macrophylla*)	*Bacillus licheniformis* *Micrococcus* spp. *Staphylococcus* spp.	Delicacy usually consumed with stock fish or dried fish
Palm wine	Palm sap	*Saccharomyces* spp. Lactic acid bacteria Acetic acid bacteria	Alcoholic drink
Burukutu/Pito/Otika	Sorghum Millet &maize	*Saccharomyces* spp. Lactic acid bacteria	Alcoholic drink
Shekete	Maize	*Saccharomyces* spp.	Alcoholic drink
Agadagidi	Plantain	*Saccharomyces* spp.	Alcoholic drink

Importance of fermentation

- Apart from detoxification by the elimination of naturally-occurring nutritional stress factors, other benefits of traditional fermentations include reduction of mycotoxins such as aflatoxins as in ogi processing
- the conversion of otherwise inedible plant items such as African locust bean (*Parkia biglobosa* Jacq) and African oil bean (*Pentaclethra macrophylla* Benth) to foods, i.e. iru and ugba respectively, by extensive hydrolysis of their indigestible components by microbial enzymes.
- Fermentation improves the flavor and texture of raw agricultural produce, imparting a desirable sour taste to many foods, such as gari and ogi, and leading to the production of distinct flavor components characteristic of many fermented foods.
- Fermentation may lead to significant improvement in the nutritional quality of foods by increasing the digestibility of proteins through hydrolysis of proteins to amino acids, increasing bio-availability of minerals such as calcium, phosphorus, zinc and iron through hydrolysis of complexing agents such as phytate and oxalate, and increasing nutrient levels, especially B-vitamins, through microbial synthesis

3.4 Challenges of processing crop produce

The foregoing discussions reveal that significant amounts of post-harvest losses affected the economy and welfare of farmers, consumers, and traders. Therefore, some of the important socio-economic and technological issues of post-harvest processing and preservation need to be considered to reduce post-harvest losses.

These include.

Size of land holding: The size of land holding has a significant effect on the extent of post-harvest losses at the farm and different handling points. A comparative study on of the various post-harvest practices among small, medium, and large farms would enable researchers and policy makers to identify the appropriate post-harvest loss reducing technologies for specific group of farmers.

Educational background and training of farmers and traders: The educational attainment of the farmer including his attendance in informal training related to postharvest technology is another factor that needs to be considered. Their participation in various seminars, workshops, and informal training on farming techniques would enable them to be receptive to the adoption of appropriate technology.

Attitude of farmers: Some investigations of the farmers' attitude disclosed that some of them are not aware of proper handling practices since they are more concerned with pre-harvest losses due to flood, drought, insect damage etc. Others view, loss or gain as the result of God's punishment or God's mercy; others associated loss to chance or bad luck etc.

Level of income of farmer: Income is very important as it affects largely the level of capital investment of farms. The income generated from farm to off-farm sources would determine whether the farmer is financially capable of reducing post-harvest losses through investment on better packaging materials or storage facilities. Low investment has been argued as the main chain effect of low income. The lack of adequate capital inhibits farmers from buying recommended containers for transport. Most often, farmers may harvest immature crops mainly fruits and vegetables during times when they need immediate cash for the family and/or when prices are high. Harvesting of immature commodities result in poor quality products.

Presence of middlemen in marketing channel: In Nigeria middlemen are the common source of financing for small farmers. Usually the rate of interest in cash or kind is very high.

A well-managed and organized cooperative is expected to reduce post-harvest losses compared with individual farmer operation.

Capital investment and financing*:* Capital investment of some middlemen like exporters, truckers, and cold storage owners is high because of high cost of buildings, vehicles, equipment and machinery and other related costs. A much higher capital investment is expected in the operation of cold storage facilities. The relationship between big capital investment and post-harvest losses, and information on postharvest practices should be collected through research.

Consumer's behavior*:* The extent of post-harvest losses at the consumer level can be related to their educational level, income, taste and preference, attitude, and family size. It is expected that the higher the educational attainment of the consumer, the lesser will be the food losses or vice-versa. The relationship between these two variables needs to be empirically tested. A few studies show that household income appears to have a strong relationship between the choice of sorted and assorted food items specially fruits and vegetables. In Metropolitan area, high-income groups prefer to purchase sorted products for assurance of good quality and convenience in preparation. Low-income groups however, prefer assorted fruits and vegetables due to lower prices. The consumers have stronger preference for freshly harvested fruits and vegetables than stored ones. The tendency of some consumers to over purchase cheap but highly perishable fruits and vegetables has led to wastage due to inadequate storage facilities.

Role of mass media*:* Dissemination of post-harvest information through the mass media as a strategy to minimize losses at the consumer level, advertisements and promotion programmes on post-harvest practices of food items should be carried-out to motivate proper attitudes towards reducing food losses.

Participation of policy makers*:* Participation of policy makers in the development of postharvest industry is essential, considering their capacity to create the required policy and climate conducive to adopting post-harvest practices. Thus, an intensive and more effective extension effort would be required by policy makers who set national priorities. Providing policy guidelines for increasing post-harvest research and development activities carried out by research institutions and universities to determine the best-suited technology at the farmer and grain processor levels is also needed.

3.4.1 Strategies for enhancing crop processing

The future strategies of post-harvest research should be determined keeping the following constraints in view:

Climatic constraints at harvesting: Rainfall at harvest time delays harvesting, threshing and drying of cereals grains. The rainfall at this time favors disease and pest infestation as well as reduces seed quality. High temperature reduces yield and increases disease incidence. Rainfall and hailstorm in the later part of winter and during summer cause reduction in millet grain yield and quality.

Harvesting, threshing, cleaning, and sorting*:* Appropriate machines need to be developed/adopted through research and extension.

Drying and field transportation systems*:* - The drying problem is acute, particularly when there is rainfall. It is a very serious problem in the eastern region of the country where the wet period is longer. The problem is more acutely felt in the case of grain legumes since they lose viability more rapidly at high humidity. Large quantities are further spoiled by fungal attack.

Storage: - In spite of some research conducted on storage of food grains, legumes and Oil seeds the most suitable storage technologies are yet to be developed. Development of home level techniques for drying and storage of various crops is required

Handling and transportation*:* Inadequate transport, lack of mechanical handling facilities, lack of mobile refrigeration facilities are some of the acute problems encountered during handling and transportation. Development of improved packaging technologies for fruits, vegetables, tubers and spices, and processed products is needed.

Processing and preservation*:* Utilization of fruits, vegetable and tuber crop wastes, extension of shelf life of fresh fruits, vegetables and spices, and home-level processing technologies should be promoted.

3.5 Future post-harvest research priorities

- Genetic manipulation for long life, diseases and environmental-stress resistant cultivars.
- Modeling cultivating conditions for high quality and long life (avoiding root stress by heat or drought).

- Environmental friendly pest control.
- Objective determination of suitable harvesting date.
- Post harvest treatments (heat, UV, irradiation CO2, chemicals) for storage ability.
- Monitoring refrigerating systems
- Optimum storage conditions as storage for tropical fruits, ornamentals, planting material, fresh pack and lightly processed produce.
- Possibilities of modified atmosphere packaging (MAP), absorption layers, inserts sensors, PP films with micropores
- Prevention of possible pathogenic organisms in MAP products.
- Adaptive control of storage conditions with biological sensors.
- Storage during transport and as quarantine measures.
- Humid forced air precooling.
- Minimum impact and vibration norms for bruising during sorting and packaging.
- Objective non destructive measuring of quality and maturity
- Environmental friendly packaging.
- Consumer and traders quality preferences in each country.
- Cost and return of the investment of post harvest technology.
- Cost and return of the investment of post harvest technologies.
- Fundamental research on senescence, ripening, respiration, ethylene effect, chilling, fermentation, superficial browning.

4.0 Conclusion

The post-harvest losses of different food items especially fruits and vegetables, are a great concern to us. Post-harvest losses due to inadequate facilities of processing and

Preservation must be given due importance to ensure the food security both at macro and micro levels. Short term preservation may be applicable to horticultural commodities that are consumed relatively soon after harvest. For them the best preservation techniques involves keeping the product alive and respiring. Shorter preservation does not involve 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 causes food deterioration.

5.0 Summary

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 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.

Fermentation is one of the oldest and most important traditional food processing and preservation techniques.

6.0 Tutor Marked Assignment (TMA)

- Describe the principles of food processing
- Describe primary, secondary and tertiary processing of crop products
- Describe processing of cassava
- Describe processing of yam
- Explain traditional food fermentation in Nigeria
- Discuss the challenges of food processing in Nigeria
- Describe the strategies to enhance post harvest research

7.0 References and Further Readings

1. A.A. Kader (ed). Postharvest technology of horticultural crops, third edition. University of California , ANR Publication 3311.
2. Adaskaveg, J.E., H. Forster, and N.F. Sommer. 2002. Principles of postharvest pathology and management of decays of edible horticultural crops. p. 196-195,
3. Batten, D. J. and Loebel, M. R. (1984). Agfacts: Lychee harvesting and post-harvest handling. New South Wales Department of Agriculture, Australia.
4. Batten, D. J. (1989) Maturity criteria for litchis (lychees). *Food Quality Preference* **1**, 149-55
5. Diane M. Barrett; (2000) processing of horticultural crops No. 37 pg.466-479
6. **D.L. Proctor**, (1994) **Grain storage techniques** Evolution and trends in developing countries **FAO AGRICULTURAL SERVICES BULLETIN No. 109**
7. D.W. Hall, (1969)"Food Storage in Developing Countries," J.R. Soc. Arts, 142: 562-579 (1969)
8. Harris, Kenton L. and Carl J. Lindblad, eds. (1976) Postharvest Grain Loss Assessment Methods - A Manual of Methods for the Evaluation of Postharvest Losses American Association of Cereals Chemists, 1976
9. Jelle Hayma. (2003) The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
10. Lisa Kitinoja and Adel A. Kader (2002) Small Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th edition). July 2002
11. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.

12. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa. World Bank Report No. 60371-AFR
13. O. Charles Aworh (2008); The Role of Traditional Food Processing Technologies In National Development: the West African Experience. International Union of Food Science & Technology (2008)
14. Post-harvest Food Losses in Developing Countries (National Academy of Sciences, Washington, D.C., USA, 1978).
15. Thompson, J.F. and Spinoglio, M. (1994). Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
16. Schulten . G. G. M (2002) Post-harvest losses in tropical Africa and their prevention Royal Tropical Institute, Amsterdam, Netherlands
17. http://www.fao.org/docrep
18. http://postharvest.ucdavis.edu
19. http://www.crcpress.com/product
20. http://www.actahort.org/books
21. http://sciencedirect.com/science/journal
22. http://www.stewartspostharvest.com

MODULE 3: STORAGE OF CROP PRODUCTS

UNIT 1: STORAGE LIFE OF HARVESTED CROP MATERIALS

Table of contents

1.0 Introduction

Harvested fresh produce is 'living' and continues to perform its metabolic functions in the post-harvest state. These metabolic functions influence greatly on the quality and shelf life of fresh produce. A basic understanding of post-harvest physiological processes and mechanisms for their control is critical for effective quality maintenance throughout horticultural supply chains to reduce losses as well as for quality product. This component describes the physiological factors that impact on the quality of horticultural produce. Knowing the physiological processes in fresh produce and factors that influence them is important in designing measures to maintain or improve quality and reduce post harvest losses.

The Post harvest quality of a product develops during growing of produce and is maintained, quality cannot be improved after harvest. Production of high quality produce hinges on good quality inputs, good cultural practices (planting, weeding, fertilizer application etc.) as well as good hygiene management during production so as to minimize microbial and/or chemical contamination of produce. Maximum post harvest quality for any cultivar can be achieved only by understanding and managing the various roles that pre-harvest factors play in post harvest quality.

2.0 Objectives

At the end of this unit you should be able to

- Describe physiological processes of fresh produce
- Describe factors that influence the physiological processes of fresh produce
- Describe the processes of water loss in fresh produce and design measures to curtail or reduce water loss process
- Describe the factors that affect the rate of respiration
- Describe pre-harvest factors that effect quality and shelf life of produce
- Explain the effect of mineral nutrition on produce quality and shelf life
- Identify and discuss those cultural practices that aid in the production of quality produce

3.1 Physiological processes of fresh produce

3.1.1 Respiration

Harvested produce is alive, which means that it is constantly respiring. Respiration involves the breakdown of carbohydrate (example sugars) and other food reserves (organic and fatty acids) in the plant or in harvested produce and results in the production of carbon dioxide, water and heat. Respiration occurs both pre- and post-harvest.

i. **Aerobic respiration**

In the post-harvest phase, respiration is supported by carbohydrate reserves of the produce; this leads to a net loss in its dry weight or negative growth. The more rapid the respiration rate, the faster the produce will consume its carbohydrate reserves, the greater will be the heat produced and the shorter will be the post-harvest life of the fruit or vegetable.

Breaking down of glucose in the presence of oxygen leading to formation of carbon dioxide, water and energy(heat) $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6H_2O$ + Heat (2830 kJ)

Carbohydrate breakdown during respiration leads to losses in food value, flavour, texture and weight, and thus to overall quality loss. Loss in weight, in particular, results in economic loss to the producer. Every effort must, therefore, be made to slow down the respiration rate of produce in order to minimise quality losses, extend shelf life and minimise economic losses to the producer.

ii. **Factors that impact on respiration rates:**

- Temperature
- Atmospheric composition
- Physical stress

a. Temperature

Temperature has a significant influence on the respiration rate of harvested produce and without doubt has the greatest impact on the deterioration of produce post-harvest. The higher the storage temperature of fresh produce, the greater is its rate of respiration. The rate of deterioration of horticultural produce increases two to three-fold with every 10°C increase in temperature

Respiration rates can be slowed by storing produce at a low temperature that does not cause physiological damage to the produce. Temperature management is pivotal to controlling respiration and to maintaining quality.

b. Atmospheric composition

Adequate levels of O_2 are required to support the process of aerobic respiration in harvested produce. The exact level of O_2 required to reduce respiration rates, while at the same time allowing aerobic respiration, varies in accordance with the commodity concerned. An O_2 level of around 2 to 3 per cent generally produces a beneficial reduction in respiration rates and in other metabolic reactions of fresh produce. Lower O_2 levels could lead to anaerobic respiration and off-flavour development as a result of alcohol formation.

Breaking down of glucose in the absence of oxygen (anaerobic respiration) leading to the formation of carbon dioxide and energy (heat)

$C_6H_{12}O_6 \quad + \; 2\ CO_2 \rightarrow 2C_2H_5OH + \text{Heat (118 kJ)}$

(Anerobic respiration)

Post-harvest handling treatments such as waxing, coating, film wrapping and controlled atmosphere packaging can be used to regulate the availability of oxygen to harvested produce and so to reduce respiration rates.

c. Physical stress

Mild physical stress can perturb the respiration rates of produce. Bruising can, for example, result in substantial increases in the respiration rate of harvested produce. The avoidance of mechanical injury through proper packaging and handling is critical to assuring produce quality.

3.1.2 Transpiration or water loss

Fresh produce contains between 70 and 95 % water and is losing water constantly to the environment in the form of water vapour. The rate of water loss varies in accordance with morphological characteristics (such as tissue structure, dimensions and number of stomata and the presence of a waxy layer) of the epidermis (skin) of the produce item, the exposed surface area of the produce and the vapour pressure deficit (VPD) between the produce and its environment. The VPD bears an inverse relationship to the relative humidity of the environment. Under conditions of low relative humidity the VPD is high and water is lost rapidly. The rate of water loss increases exponentially with increasing temperature and linearly under conditions of low relative humidity.

Water lost due to transpiration in harvested produce cannot be replaced, thus resulting in wilting, shrivelling, loss of firmness, crispiness, succulence and overall loss of freshness. These undesirable changes in appearance, texture and flavour, coupled with weight loss, greatly reduce the economic value of horticultural produce. Wilted leafy vegetables may, for example, require excessive trimming to make them marketable.

Water loss can be controlled through temperature management, packaging and adjustment of the relative humidity of the storage environment of the produce. However, care must be taken to avoid condensation of moisture on the surface of the produce, since this could contribute to the development of decay.

3.1.3 Ethylene production

Ethylene (C_2H_4) is a naturally occurring organic molecule that is a colourless gas at biological temperatures. Ethylene is synthesised in small quantities by plants and appears to co-ordinate their growth and development. It is also associated with the decomposition of wounded produce. Given its gaseous nature, ethylene readily diffuses from the sites where it is produced. Continuous synthesis is, therefore, needed for maintenance of biologically active levels of ethylene in plant tissues.

Ethylene is also an environmental pollutant, being produced by internal combustion engines, propane powered equipment, cigarette smoke and rubber materials exposed to ultra violet light.

Fresh produce can be categorised as being either climacteric or non-climacteric on the basis of its ability to produce ethylene during the ripening process.

• **Climacteric produce** – produces a burst of ethylene and shows an increase in respiration on ripening. Ripening of climacteric fruit after harvest typically involves softening and a change in colour and taste in terms of sweetness.

3.1.4 Mechanical injuries.

Various types of physical damage (surface injuries, impact bruising, and vibration bruising and so on) are major contributors to deterioration. Browning of damaged tissues results from membrane disruption, which exposes phenolic compounds to the polyphenol oxidase enzyme. Mechanical injuries not only are unsightly but also accelerate water loss, provide sites for fungal infection and stimulate CO_2 and C_2H_4 production by the commodity.

3.1.5 Pathological breakdown

One of the most common and obvious symptoms of deterioration results from the activity of bacteria and fungi. Attack by most organisms follows physical injury or physiological breakdown of commodity. In a few cases, pathogens can infect apparently healthy tissues and become the primary cause of deterioration. In general, fruits and vegetables exhibit considerable resistance to potential pathogens during most of their post harvest life. The onset of ripening in fruits and senescence in all commodities renders them susceptible to infection by pathogens. Stresses such as mechanical injuries, chilling and sunscald lower the resistance to pathogens.

3.2 Pre-harvest factors on post-harvest life

3.2. 1 Introduction

The Post harvest quality of a product develops during growing of produce and is maintained, quality cannot be improved after harvest. Therefore, the goal of a producer is to supply safe, high-quality produce, which confirms to consumer and market requirements. This objective hinges on good quality inputs, good cultural practices (planting, weeding, fertilizer application etc.) as well as good hygiene management during production so as to minimize microbial and/or chemical contamination of produce.

Pre-harvest factors often interact in complex ways that depend on specific cultivar characteristics and growth or development age sensitivities. The tremendous diversity of fruits and vegetables that are produced commercially and the general lack of research relating pre-harvest factors to post harvest quality preclude generalizations about pre harvest influences that uniformly apply to all fruits and vegetables. Maximum post harvest quality for any cultivar can be achieved only by understanding and managing the various roles that pre-harvest factors play in post harvest quality.

3.2.2 Cultivar and rootstock genotype

Cultivar and rootstock genotype have an important role in determining the taste, quality, yield, nutrient composition, and postharvest life of fruits and vegetables. The incidence and severity of decay, insect damage, and physiological disorders can be reduced by choosing the correct genotype for given environmental conditions. Breeding programs are constantly creating new cultivars and rootstocks with improved quality and better adaptability to various environmental and crop pest conditions.

Some experts consider the most important cultivar characteristic for fruits and vegetables to be disease resistance, including resistance to diseases that diminish postharvest quality. Control of some postharvest diseases may include breeding for resistance to the vector (e.g., aphid, nematode, leafhopper, or mite), rather than just for the pathogen.

Nutritional quality may also vary greatly according to cultivar. L-ascorbic acid levels in different pepper types also vary considerably. For example, in jalapeno peppers, the highest ascorbic acid levels were in Jaloro (131 mg100g-1) and the lowest were in Mitla (49 mg 100g-1). Wide variation in beta-carotene content of several cultivars of sweet potato has similarly been reported; Georgia Jet, suggested for processing, contained low concentrations of beta-carotene (6.9 mg 100g-l). There is a need to identify and develop cultivars that are suitable for processing and high in antioxidant vitamin content.

Genetic engineering can be a successful tool in altering the quality and yield of certain vegetables, but its commercial application will depend largely on consumer acceptance and food safety issues. Future advances will depend on successful team efforts between plant breeders, plant pathologists, molecular geneticists, and consumer education programs.

3.2.3 Mineral nutrition

Nutritional status is an important factor in quality at harvest and postharvest life of various fruits and vegetables. Deficiencies, excesses, or imbalances of various nutrients are known to result in disorders that can limit the storage life of many fruits and vegetables. Fertilizer application rates vary widely among growers and generally depend upon soil type, cropping history; and soil test results, which help indicate nitrogen (N), phosphorous (P), and potassium (K) requirements. To date, fertilization recommendations for fruits and vegetables have been established primarily for productivity goals, not as diagnostics for good flavor quality and optimal postharvest life.

The nutrient with the single greatest effect on fruit quality is nitrogen. Response of peach and nectarine trees to nitrogen fertilization is dramatic. High nitrogen levels stimulate vigorous vegetative growth, causing shading and death of lower fruiting wood. Although high-nitrogen trees may look healthy and lush, excess nitrogen does not increase fruit size, production, or soluble solids content (SSC). Furthermore, excessive nitrogen delays stone fruit maturity, induces poor red colour development, and inhibits ground colour change from green to yellow. However, nitrogen deficiency leads to small fruit with poor flavor and unproductive trees.

In vegetable crops, excessive nitrogen levels induce delayed maturity and increase several disorders that diminish postharvest quality. Disorders such as grey wall or internal browning in tomato, hollow stem of broccoli, lower soluble solids concentration in potato, fruit spot in peppers, and growth cracks and hollow heart in broccoli and cauliflower have been associated with high nitrogen. High nitrogen has also been associated with increased weight loss during storage of sweet potatoes and soft rot in tomatoes. Excessive soil nitrogen can negatively impact vegetable quality in several ways. High nitrogen can result in composition changes such as reduced ascorbic acid (vitamin C) content, lower sugar content, lower acidity, and altered ratios of essential amino acids. In leafy green vegetables grown under low light, it can result in the accumulation of nitrates in plant tissues to unhealthy levels. High nitrogen fertilization can lead to reduced volatile production and changes in the characteristic flavor of celery.

Although calcium (Ca) is classified as a secondary nutrient, it is involved in numerous biochemical and morphological processes in plants and has been implicated in many disorders of considerable economic importance to the production and postharvest quality of fruits and vegetables. Bitter pit in apple, corkspot in pear, blackheart in celery, blossom end rot in tomato, cavity spot and cracking in carrot, and tipburn of lettuce are calcium deficiency disorders that reduce the quality and marketability of these commodities. Certain calcium deficiency disorders, such as bitter pit in apples and blossom end rot in tomatoes, may be lessened through proper irrigation, fertilizer management, and supplemental fertilization.

However, for tip bum of lettuce, a physiological disorder caused by the lack of mobility of calcium in the heads during warm weather and rapid growing conditions, there is currently no pre-harvest control practice.

3.2.4 Irrigation

Despite the important role of water in fruit growth and development, few studies have been done on the influence of the amount and the timing of water applications on fruit and vegetable quality at harvest and during postharvest.

Water management as a direct determinant of postharvest quality has also been investigated for a number of vegetables produced in semiarid irrigated regions such as California and Israel. Except for a few studies, however, which have comprehensively tested a broad range of water management practices and conditions and their impacts on postharvest quality; it is often difficult to generalize about the effects of water management from the site-specific irrigation regimes that have been reported.

There is considerable evidence that water stress at the end of the season, which may be achieved by irrigation cutoff or deficit irrigation relative to evapotranspirative demand for generally more than 20 days prior to harvest, may markedly improve SSC in tomatoes. Irrigation cutoffs may also facilitate harvests and minimize soil compaction from mechanical harvest operations. Late-season irrigations with saline water have also been shown to increase tomato SSC. Although a higher SSC may result in premiums paid to producers, because of the link between applied water and yield, irrigation practices typically aim at the best overall economic balance between productivity and quality.

Melon postharvest quality is also quite sensitive to water management. Over irrigation can result not only in low SSC in melons but also unsightly ground spots and fruit rots (and measles in honeydews). Rapid growth resulting from irrigations following extended periods of soil water deficits may result in growth cracks in carrots, potatoes, tomatoes, and several other vegetable crops. Uneven irrigation management may also increase the incidence of "spindle"- or "dumb-bell"shaped potatoes, depending on the growth stage during which soil Water was limited. Postharvest losses due to storage diseases such as neck rot, black rot, basal rot, and bacterial rot of onions can be influenced by irrigation management. Selecting the proper irrigation system relative to the crop stage of growth, reducing the number of irrigations applied, and assuring that onions cure adequately prior to harvest can help prevent storage losses.

Management of water frequently poses a dilemma between yield and postharvest quality. A deficiency or excess of water may influence postharvest quality of berry 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 postharvest quality. In strawberries, reduction of water stress by natural rainfall or irrigation during maturation and ripening decreases firmness and sugar con- tent and provides more favorable conditions for mechanical fruit injury and rot. If straw- berry plants are over irrigated, especially at harvest, the fruit is softer and more susceptible to bruising and decay.

3.2.5 Crop rotations

Crop rotation may be an effective management practice for minimizing postharvest losses by reducing decay inoculum in a production field. Because soil borne fungi, bacteria, and nematodes can build up to damaging levels with repeated cropping of a single vegetable crop, rotations out of certain vegetables are commonly recommended in intensive vegetable production regions. Four-year rotations with noncucurbit crops are routinely recommended for cucurbit disease management, as are 4-year rotations for garlic to decrease postharvest disease incidence. There is also evidence that the use of plastic mulches can increase postharvest losses from decay in vegetables such as tomatoes.

4.0 Conclusion

A basic understanding of post-harvest physiological processes i.e. respiration, transpiration, ethylene production, pathological break down, and mechanical injuries and mechanisms for their control is critical for effective quality maintenance throughout horticultural supply chains to reduce losses as well as for quality product. This component describes the physiological factors that impact on the quality of horticultural produce. Knowing the physiological processes in fresh produce and factors that influence them is important in designing measures to maintain or improve quality and reduce post harvest losses.

The Post harvest quality of a product develops during growing of produce and is maintained, quality cannot be improved after harvest. This objective hinges on good quality inputs, good cultural practices (planting, weeding, fertilizer application etc.) as well as good hygiene management during production so as to minimize microbial and/or chemical contamination of produce. Pre-harvest factors such as good quality inputs, good cultural practices (planting, weeding, fertilizer application etc.) as well as good hygiene management during production so as to minimize microbial and/or chemical contamination of produce.

5.0 Summary

These metabolic functions (i.e. respiration, transpiration and ethylene production) influence greatly the quality and shelf life of fresh produce. A basic understanding of post-harvest physiological processes and mechanisms for their control is critical for effective quality maintenance throughout horticultural supply chains to reduce losses as well as for quality product**.** Temperature has a significant influence on the respiration rate of harvested produce and without doubt has the greatest impact on the deterioration of produce post-harvest quality. Maximum post harvest quality for any cultivar can be achieved only by understanding and managing the various roles that pre-harvest factors play in post harvest quality.

6.0 Tutor Marked Assignment (TMA)

- Describe the process of respiration and its effect on produce quality
- Explain the terms climacteric and non-climacteric fruits
- Enumerate the factors that impact on rates of respiration
- Describe the role of cultivar genotype in determining the quality of crop produce
- Explain the impact of irrigation on post harvest quality of crop produce

7.0 References and Further Reading

1. A.A. Kader (2002). Postharvest Technology of Horticultural Crops, third edition. University of California , ANR Publication 3311
2. Barkai-Golan, R. and Phillips, D.J. (1991) Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.
3. Carol Thomas (2005) Post Harvest Handling of produce. News Letter of Inter American Institute for Cooperation in Agriculture (IICA)
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. Jelle Hayma. 2003 The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
6. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. p.455-469
7. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation.
8. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
9. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.

10. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa Wold Bank Report No. 60371-AFR. April 2011

11. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California , Division of Agriculture and Natural Resources, UC Bulletin 1914.
12. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
13. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009

14. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
15. Kader A. A. (1999). Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
16. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469
17. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
18. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
19. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257, in:
20. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California, Division of Agriculture and Natural Resources, UC Bulletin 1914.
21. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
22. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
23. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .

24. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
25. Zinash Delebo OSUNDE (2008); Minimizing Postharvest Losses in Yam (*Dioscorea spp.*) Treatments and Techniques; Using Food Science and Technology to Improve Nutrition and Promote National Development, International Union of Food Science & Technology (2008)
26. http://postharvest.ucdavis.edu
27. http://www.fao.org/docrep/
28. http://www.crcpress.com/product
29. http://www.actahort.org/books
30. http://sciencedirect.com/science/journal
31. http://www.stewartspostharvest.com

UNIT 2 STORAGE AND SHELF-LIFE PROBLEMS

Table of contents

3.2.8 High pressure

4.0 Conclusion

5.0 Summary

6.0 Tutor Marked Assignment (TMA)

7.0 References and Further Readings

1.0 Introduction

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

2.0 Objectives

At the end of this unit you should be able to answer the following questions

- Describe ideal temperature and relative humidity for the storage of most fruits and vegetables
- Suggest measures that could minimize primary loss of crop produce
- Describe problems of crop storage

- Carry out storage of some crop produce based on the knowledge acquired in this unit
- Describe methods of shelf-life extension of crop produce by canning
- Describe drying as a method of extending shelf life of crop produce
- Describe freezing as a method of shelf life extension

3.0 Problems of crop storage

i. Temperature

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

ii. Moisture

Moisture may enter the storage container via the ground, the walls or the roof. A good overhanging roof protects the walls against rain. In order to prevent moisture coming up from the ground, the gourds, baskets, sacks etc. should always be placed on a dry under floor or on a platform of bricks or wooden poles. Floors of stone or concrete can be laid on a moisture barrier made of metal foil, tar paper, plastic and/or should have a waterproof layer of cement of 1 cm thickness (weight ratio water: cement: sand = 0.3:1:3). During storage in the rainy season moisture from the air can also enter via the walls of the silo, unless this is taken into account when choosing and building the silo (airtight storage).

iii. Insects

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

Prevent further development of the insects by:

- Airtight storage
- Sunning. Insects leave grain which is placed in hot sunlight as they do not like temperatures higher than 40 - 50 °C. The sunning process, however, does not always kill eggs and larvae present inside the grain itself.

- Mixing the grains with wood ash (or ash of burned rice husks), burned cow dung, fine sand, lime, diatomaceous earth or certain types of kaolin clay. Volume ratios of ash:grain = 1:1 to 1:2, and clay: grain = 1:10. The effect of kaolin clay is greatly enhanced if sulphuric or hydrochloric acid is added and subsequently heated to 400 °C. The materials used, fill the spaces between the grains, thereby restricting

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

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

iv. Domestic animals

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

v. Thieves

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

3.1 Recommended Temperature and Relative Humidity, and Approximate Transit and Storage Life for Fruits and Vegetable Crops

Table 1.3.2 Recommended Temperature and Relative Humidity, and Approximate Transit and Storage Life for Fruits and Vegetable Crops

Product	Temperature		Relative Humidity (percent)	Approximate storage life
	°C	°F		
Amaranth	0-2	32-36	95-100	10-14 days
Anise	0-2	32-36	90-95	2-3 weeks
Apples	-1-4	30-40	90-95	1-12 months
Apricots	-0.5-0	31-32	90-95	1-3 weeks
Artichokes, globe	0	32	95-100	2-3 weeks
Asian pear	1	34	90-95	5-6 months
Asparagus	0-2	32-35	95-100	2-3 weeks
Atemoya	13	55	85-90	4-6 weeks
Avocados, Fuerte, Hass	7	45	85-90	2 weeks
Avocados, Lula, Booth-1	4	40	90-95	4-8 weeks
Avocados, Fuchs, Pollock	13	55	85-90	2 weeks

Babaco	7	45	85-90	1-3 weeks
Bananas, green	13-14	56-58	90-95	14 weeks
Barbados cherry	0	32	85-90	7-8 weeks
Bean sprouts	0	32	95-100	7-9 days
Beans, dry	4-10	40-50	40-50	6-10 months
Beans, green or snap	4-7	40-45	95	7-10 days
Beans, lima , in pods	5-6	41-43	95	5 days
Beets, bunched	0	32	98-100	10-14 days
Beets, topped	0	32	98-100	4-6 months
Belgian endive	2-3	36-38	95-98	24 weeks
Bitter melon	12-13	53-55	85-90	2-3 weeks
Black sapote	13-15	55-60	85-90	2-3 weeks
Blackberries	-0.5-0	31-32	90-95	2-3 days
Blood orange	4-7	40-44	90-95	3-8 weeks
Blueberries	-0.5-0	31-32	90-95	2 weeks
Bok choy	0	32	95-100	3 weeks
Boniato	13-15	55-60	85-90	4-5 months
Breadfruit	13-15	55-60	85-90	2-6 weeks
Broccoli	0	32	95-100	10-14 days
Brussels sprouts	0	32	95-100	3-5 weeks
Cabbage, early	0	32	98-100	3-6 weeks
Cabbage, late	0	32	98-100	5-6 months
Cactus Leaves	2-4	36-40	90-95	3 weeks
Cactus Pear	2-4	36-40	90-95	3 weeks
Caimito	3	38	90	3 weeks
Calabaza	10-13	50-55	50-70	2-3 months
Calamondin	9-10	48-50	90	2 weeks
Canistel	13-15	55-60	85-90	3 weeks
Cantaloupes (3/4-slip)	2-5	36-41	95	15 days
Cantaloupes (full-slip)	0-2	32-36	95	5-14 days
Carambola	9-10	48-50	85-90	3-4 weeks
Carrots, bunched	0	32	95-100	2 weeks
Carrots, mature	0	32	98-100	7-9 months
Carrots, immature	0	32	98-100	4-6 weeks
Cashew apple	0-2	32-36	85-90	5 weeks
Cauliflower	0	32	95-98	34 weeks
Celeriac	0	32	97-99	6-8 months
Celery	0	32	98-100	2-3 months
Chard	0	32	95-100	10-14 days
Chayote squash	7	45	85-90	4-6 weeks
Cherimoya	13	55	90-95	2-4 weeks
Cherries, sour	0	32	90-95	3-7 days
Cherries, sweet	-1 to -0.5	30-31	90-95	2-3 weeks

Chinese broccoli	0	32	95-100	10-14 days
Chinese cabbage	0	32	95-100	2-3 months
Chinese long bean	4-7	40-45	90-95	7-10 days
Clementine	4	40	90-95	24 weeks
Coconuts	0-1.5	32-35	80-85	1-2 months
Collards	0	32	95-100	10-14 days
Corn, sweet	0	32	95-98	5-8 days
Cranberries	2-4	36-40	90-95	24 months
Cucumbers	10-13	50-55	95	10-14 days
Currants	-0.5-0	31-32	90-95	1-4 weeks
Custard apples	5-7	41-45	85-90	4-6 weeks
Daikon	0-1	32-34	95-100	4 months
Dates	-18 or 0	0 or 32	75	6-12 months
Dewberries	-0.5-0	31-32	90-95	2-3 days
Durian	4-6	39-42	85-90	6-8 weeks
Eggplants	12	54	90-95	1 week
Elderberries	-0.5-0	31-32	90-95	1-2 weeks
Endive and escarole	0	32	95-100	2-3 weeks
Feijoa	5-10	41-50	90	2-3 weeks
Figs fresh	-0.5-0	31-32	85-90	7-10 days
Garlic	0	32	65-70	6-7 months
Ginger root	13	55	65	6 months
Gooseberries	-0.5-0	31-32	90-95	34 weeks
Granadilla	10	50	85-90	3-4 weeks
Grapefruit, Calif. & Ariz.	14-15	58-60	85-90	6-8 weeks
Grapefruit, Fla. & Texas	10-15	50-60	85-90	6-8 weeks
Grapes, Vinifera	-1 to -0.5	30-31	90-95	1-6 months
Grapes, American	-0.5-0	31-32	85	2-8 weeks
Greens, leafy	0	32	95-100	10-14 days
Guavas	5-10	41-50	90	2-3 weeks
Haricot vert (fine beans)	4-7	40-45	95	7-10 days
Horseradish	-1-0	30-32	98-100	10-12 months
Jaboticaba	13-15	55-60	90-95	2-3 days
Jackfruit	13	55	85-90	2-6 weeks
Jaffa orange	8-10	46-50	85-90	8-12 weeks
Japanese eggplant	8-12	46-54	90-95	1 week
Jerusalem Artichoke	-0.5-0	31-32	90-95	+5 months
Jicama	13-18	55-65	65-70	1-2 months
Kale	0	32	95-100	2-3 weeks
Kiwano	10-15	50-60	90	6 months
Kiwifruit	0	32	90-95	3-5 months
Kohlrabi	0	32	98-100	2-3 months
Kumquats	4	40	90-95	2-4 weeks

Langsat	11-14	52-58	85-90	2 weeks
Leeks	0	32	95-100	2-3 months
Lemons	10-13	50-55	85-90	1-6 months
Lettuce	0	32	98-100	2-3 weeks
Limes	9-10	48-50	85-90	6-8 weeks
Lo bok	0-1.5	32-35	95-100	24 months
Loganberries	-0.5-0	31-32	90-95	2-3 days
Longan	1.5	35	90-95	3-5 weeks
Loquats	0	32	90	3 weeks
Lychees	1.5	35	90-95	3-5 weeks
Malanga	7	45	70-80	3 months
Mamey	13-15	55-60	90-95	2-6 weeks
Mangoes	13	55	85-90	2-3 weeks
Mangosteen	13	55	85-90	2-4 weeks
Melons:				
Casaba	10	50	90-95	3 weeks
Crenshaw	7	45	90-95	2 weeks
Honeydew	7	45	90-95	3 weeks
Persian	7	45	90-95	2 weeks
Mushrooms	0	32	95	34 days
Nectarines	-0.5-0	31-32	90-95	2-4 weeks
Okra	7-10	45-50	90-95	7-10 days
Olives, fresh	5-10	41-50	85-90	+6 weeks
Onions, green	0	32	95-100	34 weeks
Onions, dry	0	32	65-70	1-8 months
Onion sets	0	32	65-70	6-8 months
Oranges , Calif. & Ariz.	3-9	38-48	85-90	3-8 weeks
Oranges , Fla. & Texas	0-1	32-34	85-90	8-12 weeks
Papayas	7-13	45-55	85-90	1-3 weeks
Passionfruit	7-10	45-50	85-90	3-5 weeks
Parsley	0	32	95-100	2-2.5 months
Parsnips	0	32	95-100	+6 months
Peaches	-0.5-0	31-32	90-95	2-4 weeks
Pears	-1.5 to -0.5	29-31	90-95	2-7 months
Peas, green	0	32	95-98	1-2 weeks
Peas, southern	4-5	40-41	95	6-8 days
Pepino	4	40	85-90	1 month
Peppers, Chili (dry)	0-10	32-50	60-70	6 months
Peppers, sweet	7-13	45-55	90-95	2-3 weeks
Persimmons, Japanese	-1	30	90	34 months
Pineapples	7-13	45-55	85-90	24 weeks
Plantain	13-14	55-58	90-95	1-5 weeks
Plums and prunes	-0.5-0	31-32	90-95	2-5 weeks

Pomegranates	5	41	90-95	2-3 months
Potatoes, early crop	10-16	50-60	90-95	10-14 days
Potatoes, late crop	4.5-13	40-55	90-95	5-10 months
Pummelo	7-9	45-48	85-90	12 weeks
Pumpkins	10-13	50-55	50-70	2-3 months
Quinces	-0.5-0	31-32	90	2-3 months
Raddichio	0-1	32-34	95-100	2-3 weeks
Radishes, spring	0	32	95-100	34 weeks
Radishes, winter	0	32	95-100	24 months
Rambutan	12	54	90-95	1-3 weeks
Raspberries	-0.5-0	31-32	90-95	2-3 days
Rhubarb	0	32	95-100	24 weeks
Rutabagas	0	32	98-100	+6 months
Salsify	0	32	95-98	2-4 months
Santol	7-9	45-48	85-90	3 weeks
Sapodilla	16-20	60-68	85-90	2-3 weeks
Scorzonera	0-1	32-34	95-98	6 months
Seedless cucumbers	10-13	50-55	85-90	10-14 days
Snow peas	0-1	32-34	90-95	1-2 weeks
Soursop	13	55	85-90	1-2 weeks
Spinach	0	32	95-100	10-14 days
Squashes, summer	5-10	41-50	95	1-2 weeks
Squashes, winter	10	50	50-70	2-3 months
Strawberries	0	32	90-95	5-7 days
Sugar apples	7	45	85-90	4 weeks
Sweetpotatoes	13-15	55-60	85-90	4-7 months
Tamarillos	3-4	37-40	85-95	10 weeks
Tamarinds	7	45	90-95	3-4 weeks
Tangerines, mandarins, and related citrus fruits	4	40	90-95	24 weeks
Taro root	7-10	45-50	85-90	4-5 months
Tomatillos	13-15	55-60	85-90	3 weeks
Tomatoes, mature-green	18-22	65-72	90-95	1-3 weeks
Tomatoes, firm-ripe	13-15	55-60	90-95	4-7 days
Turnips	0	32	95	4-5 months
Turnip greens	0	32	95-100	10-14 days
Ugli fruit	4	40	90-95	2-3 weeks
Waterchestnuts	0-2	32-36	98-100	1-2 months
Watercress	0	32	95-100	2-3 weeks
Watermelons	10-15	50-60	90	2-3 weeks
White sapote	19-21	67-70	85-90	2-3 weeks
White asparagus	0-2	32-36	95-100	2-3 weeks
Winged bean	10	50	90	4 weeks
Yams	16	61	70-80	6-7 months

Yucca root	0-5	32-41	85-90	1-2 months

Source: McGregor, B.M. 1989. Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.

3.2 Methods of Shelf life extension

3.2.1 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 number of methods are used: pasteurization, boiling (and other applications of high temperature over a period of 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, osmotic ally 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 more than 4.6) need sterilization under high temperature (116-130°C). To achieve temperatures above the boiling point requires the use of a pressure canner. Foods that must be pressure canned 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.

3.2.2 Drying

One of the oldest methods of Shelf life extension is by 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.

3.2.3 Freezing

Freezing is also one of the most commonly used processes commercially and domestically for preserving a very wide range of food including prepared food stuffs 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.

3.2.4 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 loss of flavor from oxidation.

3.2.5 Sugar

Sugar is used to preserve fruits, either in syrup with fruit such as apples, pears, peaches, apricots, plums or in crystallized form where the preserved material is cooked in sugar to the point of crystallisation 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 glacé fruit such as glacé 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 preservation of luxury products such as fruit in brandy or other spirits. These should not be confused with fruit flavored spirits such as cherry brandy or Sloe gin.

3.2.6 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 occur 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 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 micro-organisms. Most such failures are rapidly detected as decomposition within the can causes 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.

3.2.7 Pulsed Electric Field Processing

Pulsed electric field (PEF) processing is a method for processing cells by means of 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.

3.2.8 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.

4.0 Conclusion

Anything that increases the rate at which a product's food and water reserves are used up increases the likelihood of losses. Increases in normal physiological changes can be caused by high temperature, low atmospheric humidity and physical injury. Such injury often results from careless handling, causing internal bruising, splitting and skin breaks, thus rapidly increasing water loss. To prevent the food from being spoiled before and during containment, quite a number of methods are used: pasteurization, boiling (and other applications of high temperature over a period of 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, osmotic ally extreme (for example very sugary) or other microbe-challenging environments.

5.0 Summary

There are so many causes for losses in the post-harvest food chain that it helps to classify them into two groups primary and secondary causes of loss. Microbiological, mechanical and physiological factors cause most of the losses in perishable crops. Respiration is a continuing process in a plant and cannot be stopped without damage to the growing plant or harvested produce. It uses stored starch or sugar and stops when reserves of these are exhausted, leading to ageing and loss of quality. To prevent the food from being spoiled before and during containment, quite a number of methods are used: pasteurization, boiling (and other applications of high temperature over a period of 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, osmotic ally extreme (for example very sugary) or other microbe-challenging environments.

6.0 Tutor Marked Assignment (TMA)

- Describe the problems encountered during storage of crop produce
- Describe canning as a method of shelf life extension
- Describe drying as a method of shelf-life extension

– Describe freezing as a method of shelf-life extension
– Describe high pressure as a method of shelf-life extension

7.0 References and Further Readings

1. A.A. Kader (2002). Postharvest Technology of Horticultural Crops, third edition. University of California , ANR Publication 3311
2. Barkai-Golan, R. and Phillips, D.J. (1991) Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.
3. Carol Thomas (2005) Post Harvest Handling of produce. News Letter of Inter American Institute for Cooperation in Agriculture (IICA)
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
6. Jelle Hayma. (2003) The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
7. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
8. Kader A. A. (1999). Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
9. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation.
10. Lisa Kitinoja and Adel A. Kader (2003). Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis

11. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
12. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa Wold Bank Report No. 60371-AFR. April 2011
13. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257, in:
14. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California , Division of Agriculture and Natural Resources, UC Bulletin 1914.
15. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
16. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
17. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
18. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
19. Zinash Delebo OSUNDE (2008); Minimizing Postharvest Losses in Yam (*Dioscorea spp.*) Treatments and Techniques; Using Food Science and Technology to Improve Nutrition and Promote National Development, International Union of Food Science & Technology (2008)
20. http://postharvest.ucdavis.edu
21. http://www.fao.org/docrep/
22. http://www.crcpress.com/product
23. http://www.actahort.org/books
24. http://sciencedirect.com/science/journal
25. http://www.stewartspostharvest.com

UNIT 3: METHODS OF CROP PRODUCT STORAGE

Table of contents

1.0 Introduction

High temperature and high moisture are the most significant factors affecting grain quality in storage. Each can cause rapid decline in germination, malting quality, baking quality, colour, oil composition, and many other quality characteristics. When dried to moisture contents below the safe moisture level, cereals and pulses can be stored for periods of a year or more under a wide range of temperatures, provided that during storage the moisture level does not rise, and precautions against insects are taken.
Crops producing root or stem tubers, have special requirements with respect to storage, because of the high moisture content of the tubers (60 - 80% when fresh)

The following two factors, that is the moisture content of the product when it comes from the field and the relative humidity of the outside air during the storage period, determine the choice for the best storage

2.0 Objectives

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

- Describe the storage process of cereals and pulses
- Describe the storage processes of root and tuber crops
- Describe the storage processes of oil crops
- Effectively store different types of crop produce
- Describe the different methods of preserving crop produce
- Explain the latest handling procedures for crop produce
- Describe chemical method of preservation of crop produce
- Preserve fruits by the dehydration
- Preserve fruit by acidification

3.0 Principles of Crop Storage

High temperature and high moisture are the most significant factors affecting grain quality in storage. Each can cause rapid decline in germination, malting quality, baking quality, colour, oil composition, and many other quality characteristics.

Insects and moulds impair the quality of grain directly by their feeding and development, and indirectly through generation of heat and moisture. High temperatures and moistures favour development of insects and moulds. Development of insects is limited by temperatures below 15°C, and by moistures below 9% in cereal grains. Development of moulds is limited by temperatures below 10°C, and by moistures below 13% in cereal grains.

Spraying with insecticides or fumigating minimises insect problems but leaves chemical residues in grain, which break down with time. Presence of residues, and their concentration, affects acceptability of the grain to markets. Some markets prefer grain without residues. Grain buyers will not knowingly accept grain treated at rates higher than those specified on the label, or within the specified withholding period.

3.1Methods of Preservation and Storage of Crop Products

3.1.1 Cereals and pulses

Conditions for storage

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

Table1:3.3 the safe moisture content for any particular grain may vary slightly depending on the variety (valid for temperatures up to valid for temperatures up to about 27 °C. Higher temperature

	Product	Safe moisture contents %
Cereals	Maize threshed yellow	13
	Maize threshed white	13.5
	Maize flour	11.5
	Paddy rice	14.0
	Husked brown rice	12.0
	Sorghum	13.5
	Millet	15.0
	Wheat	13.5
	Wheat flour	12.0
Pulses	White and kidney bean broad	15
	Cowpea	*15*
	Lentil, pea	*14*

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

Methods of Crop Storage

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

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

3.1.1.1 Temporary Storage Methods

Such methods are quite often associated with the drying of the crop, and are primarily intended to serve this purpose. They assume the function of storage only if the grain is kept in place beyond the drying period.

(i) **Aerial Storage**

Maize cobs, sorghum or millet panicles are sometimes tied in bundles, which are then suspended from tree branches, posts, or tight lines, on or inside the house. This precarious method of storage is not suitable for very small or very large quantities and does not provide protection against the weather (if outside), insects, rodents, or thieves.

(ii) **Storage on the ground, or on drying floors**

This method can only be provisional since the grain is exposed to all pests, including domestic animals, and the weather. Usually it is resorted to only if the producer is compelled to attend to some other task, or lacks means for transporting the grain to the homestead.

(iii) **Open Timber Platforms**

A platform consists essentially of a number of relatively straight poles laid horizontally on a series of upright posts. If the platform is constructed inside a building, it may be raised just 35-40 cm above ground level to facilitate cleaning and inspection. Platforms in the open may be raised at least 1 metre above ground level. They are usually rectangular in shape, but circular or polygonal platforms are common in some countries.

Grain is stored on platforms in heaps, in woven baskets or in bags. In humid countries fires may be lit under elevated platforms, to dry the produce and deter insects or other pests.

Instead of being horizontal and flat, the platform may be conical in shape, the point at the bottom. Up to 3 metres in diameter, such platforms facilitate drying because of their funnel shape: at the top they consist of a frame of horizontal poles which is square, circular or polygonal in shape, against which the timbers which form the cone rest; these timbers meet at the bottom on a wide central supporting post

Platforms with roofs (but no walls), of whatever shape or form, may be regarded as transitional types between temporary and long-term stores. In southern Benin, Togo and Ghana, for example, maize cobs in their sheaths are laid in layers on circular platforms with their tips pointing inwards. The platforms are usually between 2 and 3 metres in diameter, but some may be more than 6 metres wide, with a maximum height of 2.5 metres at the centre and 1.5 metres at the periphery. In Ghana such a granary is called an "ewe" barn

3.1.1.2 Long-term Grain Storage Methods

(i) **Storage baskets (cribs) made exclusively of plant materials**

In humid countries, where grain cannot be dried adequately prior to storage and needs to be kept well ventilated during the storage period, traditional granaries (cribs) are usually constructed entirely out of locally available plant materials: timber, reeds, bamboo, etc. Under prevailing climatic conditions most plant material rot fairly quickly, and most cribs have to be replaced every two or three years - although bamboo structures may last up to 15 years, with careful maintenance.

Basically similar to the outdoor type of platform described above, in all its variations, the traditional crib differs in always having a roof and wall(s). It may even be elevated at least one metre above ground level, with a fire maintained underneath to assist drying of the contents and, allegedly, to reduce insect infestation. However, such cribs (especially the larger ones) are more commonly raised only 40 to 50 cm above ground level.

Access to the interior of a crib is gained usually over the wall. This may involve raising the roof, but some cribs have a gap between the top of the wall and the roof to facilitate entry. Relatively few cribs have sealable gaps in the wall or floor for the removal of grain.

(ii) **Calabashes, gourds, earthenware pots**

These small capacity containers are most commonly used for storing seed and pulse grains, such as cowpeas. Having a small opening, they can be made hermetic, by sealing the walls inside and out with liquid clay and closing the mouth with stiff clay, cow dung, or a wooden (cork?) bung reinforced with cloth.

If the grain is dry (less than 12% moisture content) there there is usually no problem with this kind of storage.

(iii) **Jars**

These are large clay receptacles whose shape and capacity vary from place to place. The upper part is narrow and is closed with a flat stone or a clay lid: which is sealed in position with clay or other suitable material. Generally kept in dwellings, they serve equally for storing seeds and legumes. So that they may remain in good servicable condition, they should not be exposed to the sun and should not be either porous or cracked.

(iv) **Solid wall bins**

Such grain stores are usually associated with dry climatic conditions, under which it is possible to reduce the moisture content of the harvested grain to a satisfactory level simply by sun-drying it. Solid wall bins are therefore traditional in the Sahel region of Africa, and in southern African countries bordering on the Kalahari desert.

The base of a solid wall bin may be made of timber (an increasingly scarce resource), earth or stone. Earth is not recommended because it permits termites and rodents to enter. The better base is made of stone.

Mud or clay silos are usually round or cylindrical in shape, depending on the materials used Rectangular-shaped bins of this type are less common, because the uneven pressure of the grain inside causes cracking - especially at the corners. Clay, which is the basic material, varies in composition from one place to another. That most commonly used for such construction work is obtained from termitaries, because the termites add a secretion which gives it better plasticity. To give it added strength, certain straw materials such as rice straw may be mixed with it; while, in some countries, néré juice is added to make it almost as durable as concrete. The diversity of materials used explains why the capacities of such silos can vary from 150 kg to 10 tonnes.

In West Africa, when only clay is used, the walls are 15 to 20 cm thick: the shape is then more or less cylindrical and the construction is similar to the walls of a house. However, when the clay is strengthened as described above, the bin is usually rounder in shape and resembles a jar; with walls only 2.5 to 5 cm thick, but very strong, so that it is possible to climb on top to enter the silo for regular withdrawal of grain. The interior is often compartmented by vertical internal walls, joining at the centre on a central column which serves to support the foot when one enters the silo. The walls are rendered as smooth as possible, inside and out in such a way as not to offer refuge for insects and their larvae; fissures are sealed with liquid clay before each loading. Similarly, the angles formed by the internal partition walls and external wall are rounded for the same reasons.

In southern Africa, where the bins are commonly rectangular in plan, internal compartments are usually covered with mud-plastered timber ceilings and are accessed via sealable 'windows'. These face a short corridor leading to the exit, which may be fitted with a standard lockable door.

The roof is usually made of thatched grass, with a generous overhang to protect the mud wall(s) from erosion. Where a side door or a detachable 'cap' is not provided, the roof has to be lifted for access to the bin. Such silos can serve for 30 or even 50 years.

(v) **Underground Storage**

Practised in India, Turkey, sahelian countries and southern Africa, this method of storage is used in dry regions where the water table does not endanger the contents. Conceived for long term storage, pits vary in capacity (from a few hundred kilogrammes to 200 tonnes). Their traditional form varies from region to region: they are usually cylindrical, spherical or amphoric in shape, but other types are known. The entrance to the pit may be closed either by heaping earth or sand onto a timber cover, or by a stone sealed with mud

The advantages of this method of storage are:

- few problems with rodents and insects;
- low cost of construction compared to that of above-ground storage of similar capacity;

- ambient temperatures are relatively low and constant;
- hardly visible, and therefore relatively safe from thieves;
- no need for continuous inspection.

The disadvantages are:

- construction and digging are laborious;
- storage conditions adversely affect viability; the stored grains can only be used for consumption;
- the grain can acquire a fermented smell after long storage;
- removal of the grain is laborious and can be dangerous because of the accumulation of carbon dioxide in the pit, if it is not completely full;
- inspection of the grain is difficult;
- risks of penetration by water are not small, and the grain at the top and in contact with the walls is often mouldy, even if the rest of the stock is healthy.

3.1.2 Cassava

Conditions for storage

Root crops, crops producing root or stem tubers, have special requirements with respect to storage, because of the high moisture content of the tubers (60 - 80% when fresh). On the one hand desiccation should be avoided; on the other hand one has to guard against too much humidity around the tubers, which may cause rotting. Living tubers continue to breathe fairly intensively, and this increases at higher temperatures. When high tuber temperatures are combined with airtight storage, lack of oxygen occurs, which results for example in potatoes with black hearts. As the temperature of the product is higher better ventilation is necessary. During storage chemical changes take place in the tubers which may influence the firmness and the taste. Tubers have a dormancy of a certain period. After this dormant period they start to sprout. This period varies with the crop and the variety and the temperature of storage of the tubers. Yams can be stored for about 4 months at a normal temperature without sprouting but potatoes already start sprouting a little after 5 weeks at 15 °C. Also the tubers are often attacked by rodents during storage. Without cooling the keeping quality of tubers decreases in the following order: Yam, cocoyam, sweet potato, cassava. Also for each root crop, varieties are known that keep well and others that do not.

Cassava storage practices

- Traditionally, the problem of storage has usually been overcome by leaving the roots in the ground until needed
- and once harvested to process immediately into a dry form with a longer storage life
- The roots can be left in the ground for several months after reaching maturity but a disadvantage of this system is that large areas of land are occupied by a crop which is already mature and is thus unavailable for further use. Also the roots become more fibrous and woody and their starch content and palatability declines and in addition, susceptibility to pathogenic losses increases
- One means of storing fresh cassava roots which has been used since ancient times by the Amerindians of Amazonia is to bury the harvested roots in pits or trenches, a technique probably derived from the common practice of leaving the cassava un harvested.
- For a short period cassava roots can be kept fresh by being heaped and watered daily (and a coating of paste made from earth or mud is said to preserve the roots for four to six days

3.1.3 Yam

Curing:
Temperature 29 - 32 °C, relative humidity 90 - 95%, 4 days. Satisfactory healing only occurs around deep wounds such as knife cuts. Bruised tubers (with superficial wounds) do not respond to curing. Such tubers can only be preserved by cutting off the bruised parts before curing.

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

There are three common methods of storing yam tubers

- Barns
- On platforms

- Underground

1. The barn is the commonest form of yam storage in West Africa. It is erected in an open place and consists essentially of a series of vertically-oriented poles to which the yams are tied with rope
2. In platform storage, the yams are laid horizontally on an elevated platform.
3. Underground storage the tubers are placed together in a large ditch and then covered with soil or dry vegetation

Tips for successful yam tubers storage

- It is essential that the tubers should be well aerated and well shaded
- Tubers should be inspected frequently so that rotten ones can be removed
- The sprout should be removed from those that begin to sprout

Causes of loss during yam tuber storage

- Rotting
- Tuber respiration
- Tuber sprouting
- Moisture loss from the tubers

Cold storage for yam tubers

- Reduces storage losses due to rotting, sprouting and respiration

Limitations

- High cost of refrigeration
- Yams stored at temperatures below $10^{O}C$ tend to become brown and unsuitable for human consumption

3.1.4 Sweet potatoes

Curing:

Temperature approximately 30 °C, relative humidity 85 - 90%, 5 – 7 days. The tubers can be left in the field in small heaps that are covered at night with straw or jute sacks if the temperature drops below 25 °C.

- Curing: after harvesting but before storage, the tubers are subjected to curing, a process which promotes the healing of wounds inflicted during harvesting

- Curing is best done by subjecting the freshly harvested tubers to a temperature of 27-30^{O}C and relative humidity of 85-90% for 4–7 days in a well ventilated ware house
- Curing can be accomplish by simply leaving the tubers exposed to ambient conditions for a few days before they are packed for storage
- After curing the best condition for the storage of sweet potatoes tubers is temperature of 13-16^{O}C and relative humidity of 85-90%. The attainment of such condition requires refrigeration which may be uneconomical or unavailable
- Most farmers in Africa simply store their sweet potatoes under ambient conditions in baskets, in underground pits or in platforms.

Storage:

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

Storage Methods:

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

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

3.1.5 Potatoes

Storage condition

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

Methods of storage

- Storage in clamps or (partially) underground pits. Because the rate of respiration is still very high in the beginning the final layer of sand is sometimes applied to the straw after one week.
- Hut storage

The stores are ventilated during the night when the temperature is lower. The stores may be built partially underground with air ducts under the tubers to utilize cool night air.

- Storage in bulk or preferably in small boxes.

3.1.6 Oil-containing products (groundnut, soybean, sesame, cotton-seed, palm kernel, copra)

Oil-containing products are used for direct consumption (groundnuts, soybeans, sesame, coconut) or for the extraction of oil. Often the remaining material (the "press cake") can be used as cattle feed. The value of the oil is determined for a large part by the free fatty acid content. This influences the smell and taste of the oil in a negative way. This is especially important if the oil is used locally. The process that liberates these free fatty acids (lipolysis) goes faster at a higher temperature and humidity. The enzymes that play a role in this process are already present in these products naturally, but are produced in greater quantities when infection by insects and fungi and mechanical injury occurs. Apart from influencing taste and appearance of the dried products as well as the oil to be pressed from it, fungi can also form toxic substances like aflatoxin in groundnuts. Fungal growth on oil-containing products takes place at a moisture content above 7 – 8%

Table 2:3.3 Safe moisture content of oil-containing products.

Products	**Safe moisture content**
Groundnuts shelled	7%
Copra	7%
Palm kernels	5%
Cotton seed	10%
Soyabeans	13%

Drying

Groundnuts, soybeans and sesame are first dried in the field with the foliage still attached. Afterwards they are threshed or picked by hand. A moisture content of 15% seems the most suitable for picking by hand and threshing with flails or simple stripping machines. The latter methods give a high percentage of broken groundnuts, which increase the chance of infection by fungi and insects. When threshing mechanically, it is possible to thresh at a higher moisture content, which results in less damage. The picked or threshed products can be dried further on mats or canvas. If these products are stored in jute sacks, some additional drying will take place, provided the sacks are piled loosely. In the rainy season the additional drying should be done artificially. Storage of too moist products increases the possibility of internal heating.

Palm kernels are very difficult to store without loss of quality and have to be dried very well. For prolonged storage of coconuts the coconut meat should be dried from the original moisture content of about 50% to about 6%. The nuts are cut in half and are dried in the sun or artificially or by a combination of both. For sun-drying 60 – 80 hours of sunshine are required; if it takes longer than 10 days the coconut will spoil. They are covered at night against dew formation and during rain, or the drying racks can be stored under a roof. The meat is removed from the shell after about 2 days and 3 - 5 days are then necessary to complete the drying. Artificial drying can be done with hot air. Temperatures above 77 °C should not be used, except in the initial stage; later, the temperature is reduced to 65 °C or less. Smoke affects the quality. Before drying artificially it is advisable to dry the halved nuts in the sun for 1 or 2 days.

Storage methods

Earthen pots and gourds, baskets, jute bags and silos are suitable for storage of oil-containing products. When using the airtight methods, it is important to have a very well dried product at the beginning of the storage period. In the humid tropics methods that allow ventilation have to be used where airtight storage is not possible.

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

3.2 Technical methods of reducing food deterioration

Table 2.3.3 technical methods of reducing food deterioration

Physical	Heating
	Cooling
	Lowering of water content drying/dehydration/concentration
	Sterilising filtration
	Irradiation
	Other physical means high pressure, vacuum, inert gasses
Chemical	Salting
	Smoking
	Sugar addition
	Artificial acidification
	Ethyl alcohol addition
	Antiseptic substance action
Biochemical	Lactic fermentation (natural acidification)
	Alcoholic fermentation

From the whole list of possible methods of reducing deterioration, over the years, some procedures for fruit and vegetable preservation have found practical application.

3.3 Procedures for fruit and vegetable preservation

Table 3.3.3 Procedures for fruit and vegetable preservation

Procedures	Practical applications
Fresh storage	Fruits and vegetables
Cold storage	Fruits and vegetables
Freezing	Fruits and vegetables
Drying/dehydration	Fruits and vegetables
Concentration	Fruits and vegetables juice
Chemical preservation	Fruits semi-processed
Preservation with sugar	Fruits products/preserve
Pasteurization	Fruits and vegetables juice
Sterilization	Fruits and vegetables
Sterilizing filtration	Fruits juices
Irradiation	Fruits and vegetables

These preservation procedures have two main characteristics as far as being applied to all food products is concerned:

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

3.3.1 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, physico-chemical and organoleptic point of view, even if to a great extent the food value is assured.

Thus, heat sterilisation cannot be applied in order to destroy all micro-organisms present in foods without inducing non desirable modifications. Preservation by dehydration/drying assures microbiological stability but has the drawback of undesirable modifications that appear during storage: vitamin losses, oxidation phenomena, etc.

Starting with these considerations, the actual tendency in food preservation is to study the application of combined preservation procedures, aiming at the realisation of maximum efficiency from a microbiological and biological point of view, with reduction to a minimum of organoleptical degradation and decrease in food value.

The principles of combined preservation procedures are:

- avoid or reduce secondary (undesirable) effects in efficient procedures for microbiological preservation;
- avoid qualitative degradation appearing during storage of products preserved by efficient procedures from a microbiological point of view;
- increase microbiological efficiency of preservation procedures by supplementary means;
- combine preservation procedures in order to obtain maximum efficiency from a microbiological point of view, by specific action on various types of micro-organisms present;
- establish combined factors that act simultaneously on bacterial cells.

Fresh fruit and vegetable storage can be combined with:

- storage in controlled atmosphere where carbon dioxide and oxygen levels are monitored, increasing concentration of CO_2 and lowering that of oxygen according to fruit species. Excellent results were obtained for pomace fruit; in particular the storage period for apples has been extended. Application of this combined procedure requires airtight storage rooms.
- storage in an environment containing ethylene oxide; this accelerates ripening in some fruit: tomatoes, bananas, mangoes, etc.

- Cold storage can be combined with storage in an environment with added of carbon dioxide, sulphur dioxide, etc. according to the nature of product to be preserved.
- Preservation by drying/dehydration can be combined with:

Freezing: fresh fruit and vegetables are dehydrated up to the point where their weight is reduced by 50% and then they are preserved by freezing.

This procedure (freeze-drying) combines the advantages of drying (reduction of volume and weight) with those of freezing (maintaining vitamins and to a large extent organoleptic properties).

A significant advantage of this process is the short drying time in so far as it is not necessary to go beyond the inflexion point of the drying curve. The finished products after defreezing and rehydration/reconstitution are of a better quality compared with products obtained by dehydration alone.

- cold storage of dried/dehydrated vegetables in order to maintain vitamin C; storage temperature can be varied with storage time and can be at -8° C for a storage time of more than one year, with a relative humidity of 70-75 %.
- packaging under vacuum or in inert gases in order to avoid action of atmospheric oxygen;, mainly for products containing beta-carotene.
- Chemical preservation: a process used intensively for prunes and which has commercial applications is to rehydrate the dried product up to 35 % using a bath containing hot 2 % potassium sorbate solution. Another possible application of this combined procedure is the initial dehydration up to 35% moisture followed by immersion in same bath as explained above; this has the advantage of reducing drying time and producing minimum qualitative degradation. Both applications suppress the dehydrated products reconstitution (rehydration) step before consumption.
- Packaging in the presence of desiccants (calcium oxide, anhydrous calcium chloride, etc.) in order to reduce water vapour content in the package, especially for powdered products.
- Preservation by concentration, carried out by evaporation, is combined with cold storage during warm season for tomato paste (when water content cannot be reduced under the limit needed to inhibit moulds and yeasts, e.g. a_w = 0.70...0.75).

Chemical preservation is combined with:

- acidification of food medium (lowering pH);
- using combined chemical preservatives.
- Preservation by lactic fermentation (natural acidification) can be combined with cold storage for pickles in order to prolong storage time or shelf-life.

- Preservation with sugar is combined with pasteurization for some preserves having a sugar content below 65%.

3.4 General procedures for fruit and vegetable preservation

Fresh storage

Fresh fruit and vegetable storage

Once fruit is harvested, any natural resistance to the action of spoiling micro-organisms is lost. Changes in enzymatic systems of the fruit also occur on harvest which may also accelerate the activity of spoilage organisms.

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 minimise growth of micro-organisms and reduce enzyme activity;
- packaging or storage to control respiration rate and ripening;
- use of preservatives to kill micro-organisms on the fruit.

A principal economic loss occurring during transportation and/or storage of produce such as fresh fruit is the degradation which occurs between the field and the ultimate destination due to the effect of respiration.

Methods to reduce such degradation are as follows:

- refrigerate the produce to reduce the rate of respiration;
- vacuum cooling;
- reduce the oxygen content of the environment in which the produce is kept to a value not above 5% of the atmosphere but above the value at which anaerobic respiration would begin. When the oxygen concentration is reduced within 60 minutes the deterioration is in practice negligible.

3.5 Recent developments in post-harvest technology of fresh fruits and vegetables

i. **Harvest maturity**. This is particularly important with fruit for export. One recent innovation is the measurement of resonant frequency of the fruit which should enable the grading out of over mature and under-mature fruit before they are packed for export.

ii. **Harvest method.** Considerable research is continuing on mechanical harvesting of perishable crops with a view to minimising damage. In fruit trees, controlling their height by use of dwarfing rootstocks, pruning and growth regulating chemicals will lead to easier, cheaper more accurate harvesting.

iii. **Handling systems**. Field packing of various vegetables for export has been carried out for many years. In the last decade or so this has been applied, in selected cases, to a few tropical fruit types. Where this system can be practiced it has considerable economic advantages in saving the cost of building, labour and equipment and can result in lower levels of damage into crops.

iv. **Pre-cooling**. Little innovation has occurred in crop pre-cooling over the last decade. However high velocity, high humidity forced air systems have continued to be developed and refined. These are suitable for all types of produce and are relatively simple to build and operate and, while not providing the speed of cooling of a vacuum or hydrocooler, have the flexibility to be used with almost all crops.

v. **Chemicals.** There is a very strong health lobby whose objective is to reduce the use of chemicals in agriculture and particularly during the post harvest period. Every year sees the prohibition of the use of commonly used post-harvest chemicals. New ways need to be developed to control post-harvest diseases, pest and sprouting.

vi. **Coatings.** Slowing down the metabolism of fruit and vegetables by coating them with a material which affects their gaseous exchange is being tested and used commercially on a number of products.

vii. **Controlled environment transport**. Recent innovations in this technique have produced great progress as a result of the development and miniaturisation of equipment to measure carbon dioxide and oxygen. Several companies now offer containers where the levels of these two gases can be controlled very precisely.

3.6 Preservation by reduction of water content: drying/dehydration and concentration

Water and water activity (a_w) in foods

Micro-organisms in a healthy growing state may contain in excess of 80% water. They get this water from the food in which they grow. If the water is removed from the food it also will transfer out of the bacterial cell and multiplication will stop. Partial drying will be less effective than total drying, though for some micro-organisms partial drying may be quite sufficient to arrest bacterial growth and multiplication.

Bacteria and yeasts generally require more moisture than moulds, and so moulds often will be found growing on semi-dry foods where bacteria and yeasts find conditions unfavourable; example are moulds growing on partially dried fruits.

Slight differences in relative humidity in the environment in which the food is kept or in the food package can make great differences in the rate of micro-organism multiplication. Since micro-organisms can live in one part of a food that may differ in moisture and other physical and chemical conditions from the food just millimetres away, we must be concerned with conditions in the "microenvironment" of the micro-organisms. Thus it is common to refer to water conditions in terms of specific activity.

The term "**water activity"** is related to relative humidity. Relative humidity is defined as the ratio of the partial pressure of water vapour in the air to the vapour pressure of pure water at the same temperature. Relative humidity refers to the atmosphere surrounding a material or solution.

Water activity or aw is a property of solutions and is the ratio of vapour pressure of the solution compared with the vapour pressure of pure water at the same temperature. Under equilibrium conditions water activity equals:

$a_w = RH / 100$

When we speak of moisture requirements of micro-organisms we really mean water activity in their immediate environment, whether this be in solution, in a particle of food or at a surface in contact with the atmosphere.

At the usual temperatures permitting microbial growth, most bacteria require a water activity in the range of about 0.90 to 1.00.

Some yeasts and moulds grow slowly at a water activity down to as low as about 0.65.

Qualitatively, water activity is a measure of unbound, free water in a system available to support biological and chemical reactions. Water activity, not absolute water content, is what bacteria, enzymes and chemical reactants encounter and are affected by at the micro-environmental level in food materials.

3.7 Preservation by drying/dehydration

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

It brings about substantial reduction in weight and volume minimising packing, storage and transportation costs and enable storability of the product under ambient temperatures, features especially important for developing countries. The sharp rise in energy costs has promoted a dramatic upsurge in interest in drying world-wide over the last decade.

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.

3.7.1 Heat and mass transfer

Dehydration involves the application of heat to vaporise water and some means of removing water vapour after its separation from the fruit/vegetable tissues. Hence it is a combined/simultaneous (heat and mass) transfer operation for which energy must be supplied.

A current of air is the most common medium for transferring heat to a drying tissue and convection is mainly involved.

The two important aspects of mass transfer are:

- the transfer of water to the surface of material being dried and
- the removal of water vapour from the surface.

In order 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 in relation to heat transfer medium (drying air);
- the physical properties of drying medium/ environment;
- the characteristics of the drying equipment.

It is generally observed with many products that the initial rate of drying is constant and then decreases, sometimes at two different rates. The drying curve is divided into the constant rate period and the falling rate period.

3.7.2 Phenomena that influence the drying process

i. **Surface area**. Generally the fruit and vegetables to be dehydrated are cut into small pieces or thin layers to speed heat and mass transfer. Subdivision speeds drying for two reasons:

- large surface areas provide more surface in contact with the heating medium (air) and more surface from which moisture can escape;
- smaller particles or thinner layers reduce the distance heat must travel to the centre of the food and reduce the distance through which moisture in the centre of the food must travel to reach the surface and escape.

ii. Temperature. The greater the temperature difference between the heating medium and the food the greater will be the rate of heat transfer into the food, which provides the driving force for moisture removal. When the heating medium is air, temperature plays a second important role.

As water is driven from the food in the form of water vapour it must be carried away, or else the moisture will create a saturated atmosphere at the food's surface which will slow down the rate of subsequent water removal. The hotter the air the more moisture it will hold before becoming saturated.

Thus, high temperature air in the vicinity of the dehydrating food will take up the moisture being driven from the food to a greater extent than will cooler air. Obviously, a greater volume of air also can take up more moisture than a lesser volume of air.

iii. Air velocity. Not only will heated air take up more moisture than cool air, but air in motion will be still more effective. Air in motion, that is, high velocity air, in addition to taking up moisture will sweep it away from the drying food's surface, preventing the moisture from creating a saturated atmosphere which would slow down subsequent moisture removal. This is why clothes dry more rapidly on a windy day.

iv. Dryness of air. When air is the drying medium of food, the drier the air the more rapid is the rate of drying. Dry air is capable of absorbing and holding moisture. Moist air is closer to saturation and so can absorb and hold less additional moisture than if it were dry. But the dryness of the air also determines how low a moisture content the food product can be dried to.

v. Atmospheric pressure and vacuum. If food is placed in a heated vacuum chamber the moisture can be removed from the food at a lower temperature than without a vacuum. Alternatively, for a given temperature, with or without vacuum, the rate of water removal from the food will be greater in the vacuum. Lower drying temperatures and shorter drying times are especially important in the case of heat-sensitive foods.

vi. Evaporation and temperature. As water evaporates from a surface it cools the surface. The cooling is largely the result of absorption by the water of the latent heat of phase change from liquid to gas.

In doing this the heat is taken from the drying air or the heating surface and from the hot food, and so the food piece or droplet is cooled.

vii. Time and temperature. Since all important methods of food dehydration employ heat, and food constituents are sensitive to heat, compromises must be made between maximum possible drying rate and maintenance of food quality.

As is the case in the use of heat for pasteurization and sterilisation, with few exceptions drying processes which employ high temperatures for short times do less damage to food than drying processes employing lower temperatures for longer times.

Thus, vegetable pieces dried in a properly designed oven in four hours would retain greater quality than the same products sun dried over two days.

Several drying processes will achieve dehydration in a matter of minutes or even less if the food is sufficiently subdivided.

3.7.3 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.

While sun drying of fruit crops is still practiced for certain fruit such as prunes, figs, apricots, grapes and dates, atmospheric dehydration processes are used for apples, prunes, and several vegetables; continuous processes as tunnel, belt trough, fluidised bed and foam-mat drying are mainly used for vegetables.

Spray drying is suitable for fruit juice concentrates and vacuum dehydration processes are useful for low moisture / high sugar fruits like peaches, pears and apricots.

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 dried product;
- necessary operating conditions;
- operation costs.

There are three basic types of drying process:

- sun drying and solar drying;
- atmospheric drying including batch (kiln, tower and cabinet dryers) and continuous (tunnel, belt, belt-trough, fluidised bed, explosion puff, foam-mat, spray, drum and microwave);
- sub-atmospheric dehydration (vacuum shelf/belt/drum and freeze dryers).

The scope has been expanded to include use of low temperature, low energy process like osmotic dehydration.

As far dryers are concerned, one useful division of dryer types separates them into air convection dryers, drum or roller dryers, and vacuum dryers.

Table 4.3.3 Common dryer types used for liquid and solid foods.

Dryer type	**Usual food type**
Air convection dryers	
kiln	pieces
Cabinet, tray or pan	pieces, purées, liquids
Tunnel	pieces
Continuous conveyor belt	purées, liquids
Belt trough	pieces
Air lift	small pieces, granules
Fluidized bed	small pieces, granules
Spray	liquid, purées
Drum or roller dryers	
Atmospheric	purées, liquids
Vacuum	purées, liquids
Vacuum dryers	
Vacuum shelf	pieces, purées, liquids
Vacuum belt	purées, liquids
freeze dryers	pieces, liquids

Source: Potter, 1984

3.7.4 Fruit and vegetable natural drying - sun and solar drying

Surplus production and specifically grown 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 grower, farmer, cooperative, 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 produce cannot be used for natural drying.

Dried fruit and vegetables have certain **advantages** over those preserved by other methods. They are lighter in weight than their corresponding fresh produce and, at the same time, 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.

Different lots at various stages of maturity (ripeness) must NOT be mixed together; this would result in a poor dried product. Some varieties of fruit and vegetables are better for natural drying than other; they must be able to withstand natural drying without their texture becoming tough so that they are not difficult to reconstitute. Some varieties are unsuitable because they have irregular shape and there is a lot of wastage in trimming and cutting such varieties.

Damaged parts which have been attacked by insects, rodents, diseases, etc. and parts which 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. After trimming, the greater part of the fruit and vegetables cut into even slices of about 3 to 7 mm thick or in halves/quarters, etc.

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 discoloration 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.

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 a dust storm or rain, the drying trays should be stacked together and placed under cover.

In order 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. All materials should be dried on trays designed for the purpose; the most common drying trays have wooden frames with a fitted base of nylon mosquito netting. Mesh made of woven grass can also be used. Metal netting must NOT be used because it discolours the product.

The trays should be placed on a framework at table height from the ground. This allows the air to circulate freely around the drying material and it also keeps the food product well away from dirt. Ideally the area should be exposed to wind and this speed up drying, but this can only be done if the wind is free of dust.

3.7.5 Blanching - exposing fruit and vegetable to hot or boiling water - as a pre-treatment before drying has the following advantages:

- it helps clean the material and reduce the amount 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 the 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.

3.8 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 fresh preservative solution of 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 being changed into pheophytin which is unattractive brownish-green.

The preservative solutions in the fruit and vegetable pre-treatment can only be used in enamelled, plastic or stainless-steel containers; never use ordinary metal because solutions will corrode this type of container.

As a general rule, **preservatives are not used for treating onions, garlic, leeks, chilies and herbs**

3.9 Chemical preservation

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

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).

This approach minimizes undesirable changes in product properties and reduces concentration of additives and 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, alcohols 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.

3.9.1 Traditional chemical food preservatives and their use in fruit and vegetable processing technologies could be summarised as follows:

- common salt: brined vegetables;
- sugars (sucrose, glucose, fructose and syrups):
- foods preserved by high sugar concentrations: jellies, preserves, syrups, juice concentrates;
- interaction of sugar with other ingredients or processes such as drying and heating;
- indirect food preservation by sugar in products where fermentation is important (naturally acidified pickles and sauerkraut).
- Acidulants and other preservatives formed in or added to fruit and vegetable products are as follows:
- Lactic acid. This acid is the main product of many food fermentations; it is formed by microbial degradation of sugars in products such as sauerkraut and pickles. The acid produced in such fermentations decreases the pH to levels unfavourable for growth of spoilage organisms such as putrefactive anaerobes and butyric-acid-producing bacteria. Yeasts and moulds that can grow at such pH levels can be controlled by the inclusion of other preservatives such as sorbate and benzoate.
- Acetic acid. Acetic acid is a general preservative inhibiting many species of bacteria, yeasts and to a lesser extent moulds. It is also a product of the lactic-acid fermentation, and its preservative action even at identical pH levels is greater than that of lactic acid. The main applications of vinegar (acetic acid) includes products such as pickles, sauces and ketchup.
- Other acidulants

- Malic and tartaric (tartric) acids is used in some countries mainly to acidify and preserve fruit sugar preserves, jams, jellies, etc.
- Citric acid is the main acid found naturally in citrus fruits; it is widely used (in carbonated beverages) and as an acidifying agent of foods because of its unique flavour properties. It has an unlimited acceptable daily intake and is highly soluble in water. It is a less effective antimicrobial agent than other acids.

- Ascorbic acid or vitamin C, its isomer isoascorbic or erythorbic acid and their salts are highly soluble in water and safe to use in foods.
- Commonly used lipophilic acid food preservatives
- Benzoic acid in the form of its sodium salt, constitutes one of the most common chemical food preservative. Sodium benzoate is a common preservative in acid or acidified foods such as fruit juices, syrups, jams and jellies, sauerkraut, pickles, preserves, fruit cocktails, etc. Yeasts are inhibited by benzoate to a greater extent than are moulds and bacteria.
- Sorbic acid is generally considered non toxic and is metabolised; among other common food preservatives the WHO has set the highest acceptable daily intake (25 mg/kg body weight) for sorbic acid. Sorbic acid and its salts are practically tasteless and odourless in foods, when used at reasonable levels (< 0.3 %) and their antimicrobial activity is generally adequate.

– Sorbates are used for mould and yeast inhibition in a variety of foods including fruits and vegetables, fruit juices, pickles, sauerkraut, syrups, jellies, jams, preserves, high moisture dehydrated fruits, etc. Potassium sorbate, a white, fluffy powder, is very soluble in water (over 50%) and when added to acid foods it is hydrolysed to the acid form. Sodium and calcium sorbates also have preservative activities but their application is limited compared to that for the potassium salt, which is employed because of its stability, general ease of preparation and water solubility.

3.9.2 Gaseous chemical food preservatives

2. Sulphur dioxide and sulphites. Sulphur dioxide (SO_2) has been used for many centuries as a fumigant and especially as a wine preservative. It is a colourless, suffocating, pungent-smelling, non-flammable gas and is very soluble in cold water (85 g in 100 ml at 25°C).
3. Sulphur dioxide and its various sulphites dissolve in water, and at low pH levels yield sulphurous acid, bisulphite and sulphite ions. The various sulphite salts contain 50-68% active sulphur dioxide. A pH dependent equilibrium is formed in water and the proportion of SO_2 ions increases with decreasing pH values. At pH values less than 4.0 the antimicrobial activity reaches its maximum.

4. Sulphur dioxide is used as a gas or in the form of its sulphite, bisulphite and metabisulphite salts which are powders. The gaseous form is produced either by burning Sulphur or by its release from the compressed liquefied form.
5. Metabisulphite are more stable to oxidation than bisulphites, which in turn show greater stability than sulphites.
6. The antimicrobial action of sulphur dioxide against yeasts, moulds and bacteria is selective, with some species being more resistant than others.
7. Sulphur dioxide and sulphites are used in the preservation of a variety of food products. In addition to wines these include dehydrated/dried fruits and vegetables, fruit juices, acid pickles, syrups, semi-processed fruit products, etc. In addition to its antimicrobial effects, sulphur dioxide is added to foods for its antioxidant and reducing properties, and to prevent enzymatic and non-enzymatic browning reactions.
8. Carbon dioxide (CO_2) is a colourless, odourless, non-combustible gas, acidic in odour and flavour. In commercial practice it is sold as a liquid under pressure (58 kg per cm^3) or solidified as dry ice.
9. Carbon dioxide is used as a solid (dry ice) in many countries as a means of low-temperature storage and transportation of food products. Beside keeping the temperature low, as it sublimes, the gaseous CO_2 inhibits growth of psychrotrophic micro-organisms and prevents spoilage of the food (fruits and vegetables, etc.).
10. Carbon dioxide is used as a direct additive in the storage of fruits and vegetables. In the controlled/ modified environment storage of fruit and vegetables, the correct combination of O_2 and CO_2 delays respiration and ripening as well as retarding mould and yeast growth. The final result is an extended storage of the products for transportation and for consumption during the off-season. The amount of CO_2 (5-10%) is determined by factors such as nature of product, variety, climate and extent of storage.
11. Chlorine. The various forms of chlorine constitute the most widely used chemical sanitiser in the food industry. These chlorine forms include chlorine (Cl_2), sodium hypochlorite (NaOCl), calcium hypochlorite ($Ca(OCl)_2$) and chlorine dioxide gas (ClO_2). These compounds are used as water adjuncts in processes such as product washing, transport, and cooling of heat-sterilised cans; in sanitising solutions for equipment surfaces, etc. Important applications of chlorine and its compounds include disinfection of drinking water and sanitation of food processing equipment.

3.9.3 General rules for chemical preservation

i. Chemical food preservatives have to be used only at a dosage level which is needed for a normal preservation and not more.
ii. Reconditioning" of chemical preserved food, e.g. a new addition of preservative in order to stop a microbiological deterioration already occurred is not recommended.
iii. The use of chemical preservatives MUST be strictly limited to those substances which are recognised as being without harmful effects on human beings' health and are accepted by national and international standards and legislation.

Factors which determine/ influence the action of chemical food preservatives

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 an "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 which 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.

The efficiency is less if the product has been contaminated because of preliminary careless hygienic treatment or an incipient alteration. Therefore, with a low initial number of micro-organisms in the product, the preservative dosage level could be reduced.

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

a. product chemical composition;
b. 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.
c. Physical presentation and size which the product is sliced to: the chemical preservative's dispersion in food has an impact on its absorption and diffusion through cell membranes on micro-organisms and this determines the preservation effect. Therefore, the smaller the slicing of the product, the higher the preservative action. Preservative dispersion is slowed down by viscous foods (concentrated fruit juices, etc.)

iv. Miscellaneous factors

a. Temperature: chemical preservative dosage level will be established as a function of product temperature and characteristics of the micro-flora;
b. Time: at preservative dosage levels in employed in industrial practice, the time period needed in order to obtain a "chemical sterilisation" is a few weeks for benzoic acid and shorter for sulphurous acid.

TABLE 5.3.3 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

For the purpose of this document, some food products in common usage are summarised as follows:

i. Citric acid: fruit juices; jams; other sugar preserves;

ii. Acetic acid: vegetable pickles; other vegetable products;

iii. Sodium benzoate: vegetable pickles; preserves; jams; jellies; semi-processed products;

iv. Sodium propionate: fruits; vegetables;

v. Potassium sorbate: fruits; vegetables; pickled products; jams, jellies;

vi. Methyl paraben: fruit products; pickles; preserves;

vii. Sulphur dioxide: fruit juices; dried / dehydrated fruits and vegetables; semi-processed products.

3.10 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 by two ways: natural acidification and artificial acidification.

3.10.1 Natural acidification.

This is achieved by a predominant lactic fermentation which assures the preservation based on acidoceno-anabiosys principle; preservation by lactic fermentation is called also biochemical preservation.

Throughout recorded history food has been preserved by fermentation. In spite of the introduction of modern preservation methods, lactic acid fermented vegetables still enjoy a 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.

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 substrate 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 is 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.

Artificial acidification

This 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 is a preservation technology which 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;

a) may be canned by processing sufficiently by heat to assure preservation in hermetically sealed containers; or

b) 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 Food and Drug Administration (FDA).

3.11 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 which 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, with the objective of obtaining a higher sugar concentration. In concentrations of 60% in the finished products, the sugar generally assures food preservation.

In the food preservation with sugar, the water activity cannot be reduced below 0.845; this value is sufficient for bacteria and neosmophile yeast inhibition but does not prevent mould attack. For this reason, various means are used to avoid mould development:

- finished product pasteurization (jams, jellies, etc.);
- use of chemical preservatives in order 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

3.12 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. **Sterilisation.** By sterilisation we mean complete destruction of micro-organisms. Because of the resistance of certain bacterial spores to heat, this frequently means a 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 sterilised, then immersing it into a 121° C pressure cooker or retort for the 15 minutes will not be sufficient because of relatively slow rate of heat transfer through the food in the can to the most distant point.
b. **"Commercially sterile"**. Term describes the condition that exists in most of 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. **Pasteurized** means 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 another 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.

3.13 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 own merit as to whether irradiation provides a technical and economical solution that is better than traditional processing methods.

Shelf-life extension. Irradiation can extend the shelf-life of foods in a number of ways. By reducing the number of spoilage organisms (bacteria, mould, fungi), irradiation can lengthen the shelf life of fruits and vegetables.

Since ionising 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 ionising radiation slows their rate of ripening. Strawberries, for example, have been found to be suitable for irradiation. Their shelf-life can be extended three-fold, from 5 to 15 days.

Disinfestation. Ionising radiation can also be used as an alternative to chemical fumigants for 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.

4.0 Conclusion

The choice of method of storage depend the moisture content of the product when it comes from the field and the relative humidity of the outside air during the storage period. Slight differences in relative humidity in the environment in which the food is kept or in the food package can make great differences in the rate of micro-organism multiplication. In practice food preservation procedures aim at avoiding microbiological and biochemical deterioration which are the principal forms of deterioration. Micro-organisms in a healthy growing state may contain in excess of 80% water. They get this water from the food in which they grow. If the water is removed from the food it also will transfer out of the bacterial cell and multiplication will stop. Partial drying will be less effective than total drying, though for some micro-organisms partial drying may be quite sufficient to arrest bacterial growth and multiplication.

5.0Summary

High temperature and high moisture are the most significant factors affecting grain quality in storage. Each can cause rapid decline in germination, malting quality, baking quality, colour, oil composition, and many other quality characteristics. Insects and moulds impair the quality of grain directly by their feeding and development, and indirectly through generation of heat and moisture. High temperatures and moistures favour development of insects and moulds. Development of insects is limited by temperatures below 15°C, and by moistures below 9% in cereal grains. Development of moulds is limited by temperatures below 10°C, and by moistures below 13% in cereal grains. Spraying with insecticides or fumigating minimises insect problems but leaves chemical residues in grain, which break down with time. Presence of residues, and their concentration, affects acceptability of the grain to markets. Various methods of storage have evolved over time and depending on crops to be stored and the environmental conditions. Food preservation techniques cold storage, freezing, drying/dehydration, sterilisation, etc are applied only to one or some categories of foods; others can be used across the board and thus a wider application. Some guarantee food preservation on their own while others require combination with other procedures, either as principal or as auxiliary processes in order to assure preservation (for example smoking has to be preceded by salting).

Exposure of fruits and vegetables to ionising radiation slows their rate of ripening, to inhibit sprouting and thereby extend the shelf life of potatoes, onions and garlic. 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)

6.0 Tutor Marked Assignment (TMA)

i. Describe food irradiation as a method of food preservation
ii. Describe heat processing as a method of food preservation
iii. Describe sugar as a means food preservation
iv. Describe the preservation of vegetables by acidification
v. Describe chemical means of preservation of fruits and vegetables
vi. Describe preservation by reduction of water content

7.0 References and Further Readings

1. A.A. Kader (2002). Postharvest Technology of Horticultural Crops, third edition. University of California , ANR Publication 3311
2. Barkai-Golan, R. and Phillips, D.J. (1991) Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.
3. Carol Thomas (2005) Post Harvest Handling of produce. News Letter of Inter American Institute for Cooperation in Agriculture (IICA)
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
6. Jelle Hayma. 2003 The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
7. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. p.455-469
8. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
9. Kader A. A. (1999). Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
10. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation.
11. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
12. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
13. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa Wold Bank Report No. 60371-AFR. April 2011
14. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257

15. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California, Division of Agriculture and Natural Resources, UC Bulletin 1914.
16. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
17. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
18. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
19. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
20. Zinash Delebo OSUNDE (2008); Minimizing Postharvest Losses in Yam (*Dioscorea spp.*) Treatments and Techniques; Using Food Science and Technology to Improve Nutrition and Promote National Development, International Union of Food Science & Technology (2008)
21. http://postharvest.ucdavis.edu
22. http://www.fao.org/docrep/
23. http://www.crcpress.com/product
24. http://www.actahort.org/books
25. http://sciencedirect.com/science/journal
26. http://www.stewartspostharvest.com
27. http://www.fda.gov

UNIT 4: IDEAL ENVIRONMENT FOR STORAGE

Table of Contents

3.3.9.1.Controlled and Modified Atmospheric Packaging (CAP and MAP)

3.3.9.2 Controlled Atmosphere (CA)

3.3.9.3 Modified Atmospheric Packaging (MAP)

3.3.9.4 Vacuum packaging

3.3.9.5 Edible Packaging

3.3.10 Packing techniques

3.3.11 Procedures to make packages more effective

3.4 Handling at whole sale and retail outlet

4.0 Conclusion

5.0 Summary

6.0 Tutor Marked Assignment (TMA)

7.0 References and Further Readings

1.0 Introduction

Temperature management is important throughout the period between harvest and consumption in order to maintain good produce quality. Cooling practices provide marketing flexibility by making it possible to market produce at the optimum time and over longer distances. Presents a variety of packing methods and packaging materials that can help to maintain product quality and reduce mechanical damage during handling, transport and storage.

2.0 Objectives

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

- Describe ideal conditions for storage of crop produce
- Explain the principles of controlled atmosphere storage
- Explain the importance of pre-cooling
- Be able to compare different pre-cooling systems
- Describe the processes that could lead to loss of quality during transportation of crop produce and the measures that could be employed in overcoming them
- To successfully transport crop produce
- Explain the importance of proper packaging and the principles involved in packaging.
- Demonstrate competence in selecting the appropriate packaging container and packaging techniques for a produce item and for different target markets.

3.0 Conditions for crop storage

Storage may be defined as the act of preserving and keeping agricultural produce or any commodity for future use without necessarily losing its quality. There should be little or no change in chemical or physical condition as to reduce its quality. Thus, the main objectives of storage is to preserve the produce such that it will still be valuable and useful to the ultimate consumer

Produce can be stored for both short-term and long-term purposes. Short-term storage is mainly used to provide flexibility in marketing (e.g. when awaiting transport), or because buyers are not immediately available. Most horticultural crops are perishable and can only be stored for a few days. Only rarely is it worthwhile storing perishable crops to await higher prices, as storage will reduce quality and shelf life whilst adding to costs. Storage is costly and, in most instances, when the produce is withdrawn from storage it has to compete in the market against much fresher produce.

A few crops are adapted for long-term storage. These can be held in store well beyond the normal harvesting period. When they are eventually sold higher prices can usually be obtained and, by extending the marketing season, a larger volume of produce can be marketed. Often, the most successful stores are located in urban areas because

If produce is to be stored, it is important to begin with a high quality product. The lot of produce must not contain damaged or diseased units, and containers must be well ventilated and strong enough to withstand stacking. In general, proper storage practices include temperature control, relative humidity control, air circulation and maintenance of space between containers for adequate ventilation, and avoiding incompatible product mixes.

Commodities stored together should be capable of tolerating the same temperature, relative humidity and level of ethylene in the storage environment. High ethylene producers (such as ripe bananas, apples, cantaloupe) can stimulate physiological changes in ethylene sensitive commodities (such as lettuce, cucumbers, carrots, potatoes, sweet potatoes) leading to often undesirable color, flavor and texture changes.

3.1 Cooling and Storage

Temperature management is important throughout the period between harvest and consumption in order to maintain good produce quality. Cooling practices provide marketing flexibility by making it possible to market produce at the optimum time and over longer distances. In order to select the best cooling method, it is necessary to understand the basic principles of cooling.

Importance of pre-cooling

Pre-cooling prior to shipment, storage or processing is essential for the removal of field heat from many perishable crops.

Proper pre-cooling can:

• prevent quality loss due to softening by suppressing enzymatic degradation and respiratory activity;

• prevent wilting by slowing or inhibiting water loss;

• slow the rate of decay of produce by slowing or inhibiting the growth of decay-producing micro-organisms (moulds and bacteria);

• reduce the rate of ethylene production; and

• minimise the impact of ethylene on ethylene sensitive produce items.

Factors that govern the selection of a pre-cooling technology

The choice of cooling methods is dependent on a number of considerations:

• Nature of the produce, e.g. fruit or vegetable – different types of produce have different cooling requirements. Strawberries and broccoli, for example, require near-freezing temperatures, whereas similarly low temperatures would damage bananas, mangoes or tomatoes.

• Package design – the level of package ventilation (i.e. number and size of ventilation holes) as well as palletisation design can greatly impact on the rate of product cooling.

• Product flow capacity – some methods of cooling are more efficient than others. Rapid cooling methods, in general, are required for the efficient cooling of large product volumes.

• Economic factors – construction and operating costs vary among cooling methods. The selection of a cooling procedure must be justified by the volume and selling price of the produce item. In cases where small volumes of produce are available and where electricity costs are high, higher-cost methods of cooling cannot be used since the cost incurred cannot be justified by the end profit margins.

• Social factors – in low-income areas and in areas that lack electricity or cooling infrastructure, the use of simple and appropriate, inexpensive cooling methods makes sense.

Pre-cooling technologies

A. Cooling with cold air

1. Room cooling

Room cooling involves exposing the produce to cold air in a refrigerated room to start the cooling process and to remove field heat. Room cooling may be used with most commodities, but may be too slow for produce that requires rapid cooling. If properly designed, a room cooling system can be relatively energy efficient.

Room cooling is very often inadequate for produce stored in large containers, such as bulk boxes or pallet loads. During the room cooling of such large containers of produce, heat is slowly removed from produce positioned near the periphery of the container. Meanwhile at the centre of the container, heat is often generated by natural respiration more rapidly than it can be removed, causing the temperature to rise.

Room cooling is also inadequate for produce requiring rapid and immediate cooling. Strawberries, for example, must be cooled as quickly as possible after harvesting if their quality is to be preserved. Even a delay of several hours may be enough to reduce their quality considerably. Room cooling is not rapid enough to prevent serious damage.

2. Forced-air cooling

Forced-air cooling makes use of fans that increase the rate of cooling in a refrigerated room by pulling cool air through packaged produce, thereby picking up heat and greatly increasing the rate of heat transfer. Although the cooling rate is dependent on the air temperature and the rate of airflow through the packages, this method is usually 75 to 90 per cent more efficient than room cooling. A number of horticultural produce items that can be cooled using forced air are listed in table 1.

Produce items that can be cooled by forced air
Anona Coconut Mango Prickly pear Avocado Cucumber Melons Pumpkin Banana Eggplant Okra Rhubarb Breadfruit Grape Orange Strawberry Brussels sprouts Grapefruit Papaya Summer squash Carambola Guava Passion fruit Tangerine Cassava Kiwifruit Pepper (Bell) Tomato Cherimoya Kumquat Persimmon Pineapple Pomegranate Litchi

B. Cooling with water

1. Hydro-cooling

Hydro-cooling is appropriate for commodities that are not sensitive to wetting. This cooling process involves the flow of chilled water over the produce, rapidly removing heat. At typical flow rates and temperature differences, water removes heat about 15 times faster than air. Hydro-cooling is only about 20-40 per cent energy efficient, as compared to 70 or 80 per cent for room and forced-air cooling, respectively.
During hydro-cooling, the produce comes into contact with water. Good water sanitation practices must, therefore, be observed during the hydro-cooling process in order to minimise contamination. Once cooled, the produce must be kept cold.
Produce packaged in wire-bound wooden crates, waxed fibreboard cartons, mesh poly bags and bulk bins can be hydro-cooled. Palletised packages can be hydro-cooled if they are carefully stacked to allow water to enter the packages. If the water flows around and not through the packages, little cooling will occur. Produce in waxed cardboard cartons with solid tops is particularly difficult to cool since the tops preclude the entry of water. Table 2 shows a range of commodities that can be subjected to hydro-cooling.

Produce that can be hydro-cooled
Artichoke Celery Peas Asparagus Chinese cabbage Pomegranate Beet Cucumber Rhubarb Broccoli Eggplant Radish Brussels sprouts Green onions Spinach Cantaloupe Kiwifruit Summer squash Carrot Leek Sweet corn Cassava Orange Swiss chard Cauliflower Parsley

2. Cooling by contact with ice

Icing is particularly effective on dense packages that cannot be cooled with forced air. Ice removes heat rapidly when first applied to produce but, unlike other cooling methods, continues to absorb heat as it melts. Because of this residual effect, icing works well with commodities such as broccoli that have high respiration rates. Icing is relatively energy efficient. One pound of ice will cool about three pounds of produce from 29.4^{o}C to 4.4^{o}C. Ice must, however, be free of chemical, physical and biological hazards.

3. Top icing

Top icing is used to cool a variety of commodities. In the top-icing process, crushed ice is added either by hand or machine over the top of the produce.

Crops that can be cooled by top icing: Broccoli Green onions Brussels sprouts Leek Cantaloupe Parsley Carrot Peas Chinese cabbage

4. Liquid icing

Liquid icing involves injecting a slurry of water and ice into produce packages through vents or handholds without de-palletising the packages or removing their tops. Growers with both small and large operations can use crushed and liquid ice cooling methods effectively. Liquid icing is an excellent cooling method, despite the fact that the produce is wet during the process. The surface of warm, wet produce, however, provides an excellent site for the development of post-harvest diseases.

5. Individual package icing

The simplest method of icing is to manually add a measured amount of crushed ice to the top of each carton filled with produce. This method is sufficient in many instances, but can result in uneven cooling since the ice generally remains in the location where it was placed until it has melted. The process is also slow and labour intensive since each carton must be opened, iced and re-closed. Individual package icing has been automated to some extent by ice-dispensing devices and the use of package conveyors and roller benches. This method of icing is not usually recommended for high-volume production.

6. Packaging containers suited for icing

Many types and sizes of fresh produce containers can be used successfully for package icing.

Popular types include waxed fibreboard cartons; wooden wire-bound crates, baskets and hampers; and perforated plastic liners. Any container that will retain its strength after wetting can be used satisfactorily for icing. Waxed fibreboard cartons are particularly well suited for icing operations. They have minimal openings, offer some insulation to help reduce the rate of melting and their strength is unaffected by wetting.

C. Vacuum cooling

Vacuum cooling is effective on produce having a high ratio of surface area to volume (see table 4). This includes produce items such as leafy greens and lettuce, which would be very difficult to cool with forced air or hydro-cooling. During the vacuum cooling process, the produce is placed inside a large metal cylinder and much of the air is evacuated. The vacuum so created causes water to evaporate rapidly from the surface of the produce, lowering its temperature. The process may cause wilting from water loss if overdone.

Crops that can be vacuum cooled: Brussels sprouts Lettuce Carrot Peas Cauliflower Snap beans Celery Spinach Chinese cabbage Sweet corn Leek Swiss chard

D. Evaporative cooling

Evaporative cooling is an appropriate, effective and inexpensive means of providing low temperature and high relative humidity conditions for cooling produce. The process involves misting or wetting produce in the presence of a stream of dry air. Evaporative cooling works best when the relative humidity of the air is less than 65 per cent. Produce should be picked during the coolest parts of the day and kept in the shade away from direct sunlight.

E. Appropriate cooling technologies

1. A solar assisted cooling chamber

A solar assisted cooling chamber that is suitable for the temporary storage of fresh fruits at the farm level is shown in figure 1. The hollow walls of the chamber, which are made of porous clay bricks, are kept moist by a water source. Evaporation of moisture from the outer surfaces of the walls, due to solar energy carried by the wind, results in drop in the temperature within the chamber by 4-5oC below ambient temperature. The moist walls of the cooler maintain a relative humidity of 85-90 per cent within the chamber. The storage life of fresh fruit stored within the chamber can be prolonged by two to three weeks.

3.2Transportation of crop produce and Factors that may compromise quality during transportation

Transportation facilitates the rapid movement of fresh produce within the horticultural supply chain. Fresh produce must be properly protected during transportation in order to minimize mechanical damage, temperature abuse, taint and contamination by food-borne pathogens. It is the responsibility of the transport provider to ensure that the transport vehicle is well maintained and is in a hygienic condition.

Transportation systems are important in moving fresh produce from production areas to distribution points.

3.2.1 Factors that may compromise quality during transportation

3.2.1.1 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.

Types of mechanical damage that occur during transportation

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

• 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

• 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 minimised 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. 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.

v. Vibration damage can be prevented, or limited, by the following practices:

• 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.
• Use rigid containers to limit the movement of the base of the container in the transport vehicle.
• Use a vehicle with a firm suspension system.
• Use radial tires, which absorb more impact than other types for road transport.

vi. Minimising mechanical damage

Mechanical damage can be minimised through the use of packaging that can withstand:
• rough handling during loading and unloading;
• compression from the overhead weight of other containers;
• impact and vibration during transportation; and
• high humidity during pre-cooling, transit and storage.

3.2.1.2 Overheating

Overheating occurs due to external sources (such as the sun, heat from the road, the walls of the vehicle etc.) as well as from heat generated by the produce 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.

i. Factors that contribute to overheating include:

• heat generated by the produce due to respiration;
• lack of ventilation, as occurs in closed vehicles;

• restricted movement of air between and through packages;
• lack of adequate ventilation in packaging; and
• exposure of packaged produce to the sun while waiting to be transported or unloaded.

ii. Overheating can be avoided by:
• use of well-ventilated vehicles;
• proper stacking to allow for the disposal of heat;
• use of well-ventilated packaging;
• avoidance of exposure to the sun on loading and off-loading tarmacs; and
• travelling early in the morning or at night if non-refrigerated transport is used.

iii. Loading patterns in transport systems to minimise overheating

Stacking patterns in transport vehicles should minimise 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.

Produce transported in cartons should be stacked to allow adequate air circulation throughout the load . The industry norm is to load palletised fruit, i.e. fruit in cartons placed on a pallet. Palletisation makes loading easier and more cost effective than loading loose cartons into the container. Palletising is usually done after other pre-cooling methods, but before forced air-cooling. Pallets must, however, be properly secured by strapping, corner bracing or net wrapping.

3.2.1.3 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 transportation vehicle in order to avoid gas build up.

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 in order to avoid the transfer of contamination from wet to dry produce.

3.2.2 Hygiene in transport systems

The quality of perishable produce 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. In order to prevent contamination by food-borne pathogens, transport systems should make use of good sanitation practices, ensure proper temperature and humidity management and minimise potential damage to the produce. It is critical that all vehicles used for transportation of food products are 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 manufacturers' recommendations.

3.2.3 Factors that govern the selection of the mode of transportation

The mode of transportation is influenced by:

- The destination of the produce
- The value of the produce
- The degree of perishability
- The volume of produce to be transported
- Recommended storage temperature and relative humidity conditions for the load
- Ambient temperature conditions at origin and destination points
- Time in transit to reach the destination by air, land or sea transport
- Road access
- Freight rates
- Quality of the transportation service

3.2.3 Transport equipment

Equipment used for the transport of fresh produce includes:

- Refrigerated and non-refrigerated vehicles – for highway transport
- Containers for air, rail and highway transport, and for lift-on/lift-off ocean transport
- Break bulk refrigerated vessels – for handling palletised loads in the refrigerated holds of vessels
- Pallets – for air cargo and highway transport

• Horse carts, donkeys

• Wheelbarrows and carts – for transportation over distances of 1-8km

Refrigerated and non-refrigerated vehicles

Refrigerated or non-refrigerated vehicles can be used for the bulk transportation of fresh produce.

i. Non-refrigerated vehicles

Non-refrigerated vehicles must provide sufficient cooling of the produce during transport. The load should be covered with a white/light-coloured canvas to avoid overheating and to allow adequate air circulation throughout the produce.

A truck-ventilating device, can be used to facilitate airflow in non-refrigerated trucks consists of wind catchers and ducts, which are constructed using wooden crates or galvanised iron. The open-ended crates are wired together into a sturdy pattern. Air flows upwards through the load during transport, so avoiding extensive overheating of the produce. Best results can be obtained if produce is transported during the early morning hours before sunrise.

ii. Refrigerated trailers

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.

iii. **Containers**

Containers are insulated metal boxes that are designed for the transport of large volumes of produce over long distances. They are generally equipped with thermometers and/or data loggers, which measure discharge air temperature at their specific locations and provide performance records of the operation of the refrigeration unit.

iv. Refrigerated containers

Refrigerated or reefer containers are generally equipped with a cooling unit, and require an external source of electricity to power the cooling unit and air circulation fans. Reefer containers are available in both 20-foot (6.1-m) and 40-foot (12.2-m) lengths. The 40-foot reefer container is the most commonly used in the fruit export industry worldwide. The 20-foot container is generally considered a relatively expensive option when compared to the 40-foot container.

Modern containers incorporate microprocessors and computers for controlling the refrigeration system. The 40-foot standard container can usually accommodate 20 ISO (International Organization of Standardisation) pallets, while the 20-footer can accommodate nine pallets.

v. Porthole containers

Porthole containers are insulated containers in which cold air is supplied by an external cooler at the required temperature. The warm air within the porthole container is extracted from the top of the load. Air flows to and from the porthole container via vents or portholes.

vi. Controlled atmosphere (CA) containers

Controlled atmosphere containers are designed to maintain the composition of the storage atmosphere around fruits within the container

Categories of CA containers:

• Refrigerated – here the containers are fitted with special equipment to maintain controlled atmosphere (CA) conditions.

• Add-on – here containers have the basic controls fitted in the refrigeration unit, but require the addition of gas and chemicals to establish and maintain CA conditions.

• Central system containers – these containers have basic fittings that need to be connected to a central plant on board the ship to establish and maintain CA conditions.

vii. Break bulk refrigerated vessels

Break bulk refrigerated vessels consist of a number of cold rooms, which can accommodate palletised produce. Between 140 and 400 pallets per cold room can be accommodated in break bulk refrigerated vessels.

viii. Palletisation

The palletisation of produce facilitates handling during shipping. Palletisation reduces damage to produce and increases the efficiency of loading and unloading operations. Plastic netting of palletised loads helps in preventing vibration and impact damage to the produce during transit.

3.3 Packing and Packaging of fresh produce

The longer the distance between the producer and the market, the greater is the cost of marketing and the requirement for proper packaging to minimise injury to produce. This section discusses packing and packaging materials and techniques that ensure produce integrity and quality.

Packing is the act of arranging or organising produce. Perishable produce may be packed on the farm where it is produced, or can be moved to another location such as a co-operative or pack house for packing. Careful handling is crucial during packing to ensure produce integrity and to maintain quality. Packing can greatly influence airflow rates around a commodity, thereby affecting its temperature and relative humidity while in transit. Produce may be either packed by hand or by using a mechanical packing system.

Packaging is a coordinated system of preparing goods for safe, secure, efficient, and effective handling, transport, distribution, storage, retailing, consumption and recovery, reuse or disposal combined with maximising consumer vale and hence profit.

3.3.1 Requirements of Packaging

The package must stand up to long distance transportation, multiple handling, and the climate changes of different storage places, transport methods and market conditions. In designing fruit packages one should consider both the physiological characteristics of the fruit as well as the whole distribution network.

The package must be capable of

- Protecting the product from the transport hazards.
- Preventing the microbial and insect damage and
- Minimizing the physiological and biochemical changes and losses in weight.

The present packaging systems for fresh vegetables in Nigeria is unsuitable and unscientific. The uses of traditional forms of packages like bamboo baskets are still prevalent. The other types of packages generally used are wooden boxes and gunnysacks. The use of corrugated fiberboard boxes is limited. The use of baskets besides being unhygienic also does not allow adequate aeration and convenience of easy handling and stocking. Considering the long term needs of eco-systems and to achieve an overall economy, other alternatives available like corrugated fibre board boxes, corrugated polypropylene board boxes, plastic trays / crates / wooden sacks, moulded pulp trays / thermoformed plastic trays and stretched film and shrink wrapping would have to be considered.

Modern packages for fresh fruits and vegetables are expected to meet a wide range of requirements, which may be summarized as follows.

i. The packages must have sufficient mechanical strength to protect the contents during handling, transport and while sacked.
ii. The construction material must not contain chemicals, which would transfer to the produce and cause toxic to it or to humans.
iii. The package must meet handling and marketing in terms of weight, size and shape.
iv. The packages should allow rapid coding of the contents.
v. The security of the package or its ease of opening and closing might be important in some marketing situations.
vi. The package should identify its contents.
vii. The package must be required to aid retail presentation.
viii. The package might need to be designed for ease of disposal, reuse or recycling.
ix. The cost of the package should be as less as possible.
x. Packaging may or may not delay or prevent fresh fruits and vegetables from spoiling. However, incorrect packaging will accelerate spoilage.
xi. Packaging should serve to protect against contamination, damage and excess moisture loss.

3.3.2The characteristics of packaging

The characteristics of packaging are to contain, to protect, to communicate and to market the product.

A. To contain produce

- As an efficient handling unit, easy to be handled by one person.
- As a marketable unit. e.g. units with the same content and weight.

B. To protect produce against

- Rough handling during loading, unloading and transport - rigid crate.
- Pressure during stacking.
- Moisture or water loss with consequent weight and appearance loss.
- Heat: air flow through crate or box via ventilation holes.

- Fumigation possible through ventilation holes.

C. To communicate:

- Identification: a label with country of origin, volume, type or variety of product, etc. printed on it.
- Marketing, advertising: recognisable trade name and trademark.

D. To market the product:

- Proper packaging will lead to reduced injuries of fruits and vegetables and subsequently to improvement of appearance.
- Standard units (weight, count) of a certain produce will increase speed and efficiency of marketing.
- With reduced costs of transport and handling, stacking and combining of packages into layer units like pallets is possible. A more efficient use of space and reduced losses will lower the marketing costs.
- Labels and slots facilitate inspection.

3.3.3 Role of Packaging in Preventing Mechanical Damage.

The four main types of mechanical damage are cuts, compression bruises, impact damage and vibration rubbing.

- **Cuts.** Care in harvesting and handling will help eliminate cuts and wounds. Lining of packaging with paper or leaves can also prevent damage to the contents.
- **Compression bruises**. These can be reduced by using containers that are strong enough to withstand multiple stacking. The packaging materials need to be particularly strong at the vertical corners. The packaging should also be shallow enough to prevent the bottom layers of produce from being damaged by the weight of produce above. Cartons must not be overfilled or damage will be caused by the full weight of the pile of produce pushing down on the top layer of fruit or vegetables, causing the weight to be transmitted to the lower layers.
- **Impact damage**. Shocks in transport or dropping of containers can result in this kind of damage. Dropping may occur either because a package is small enough to be thrown or because it is too big to be easily handled. A packing unit should not exceed 50 kg as this is

the maximum weight that can be easily handled. Package size specifications usually depend on the customers' requirements, although in many countries the supply of good packaging materials is limited and buyers may have to accept what is available.

- **Vibration rubbing**. This kind of damage generally occurs during transport. It can be significantly reduced by preventing the produce from moving within the packaging while, at the same time, ensuring that fruits or vegetables are not forced together. Fruits can be prevented from rubbing against one another by the use of cellular trays, individual wraps or cushioning pads. An example is the use of paper and straw to separate layers of apples. An alternative approach is for the container to be gently shaken, in order to settle the produce, with the space created then being filled.
- Packing materials can act as vapor barriers and can help maintain higher relative humidity within the package. In addition to protection, packaging allows quick handling throughout distribution and marketing and can minimize impacts of rough handling.

3.3.4 Packaging Materials

Packaging can be the single most expensive cost, particularly with non-returnable containers made of wood or cardboard. The benefits of packaging must clearly justify the investment. A great variety of materials are used for the packing of perishable commodities. They include wood, bamboo, rigid and foam plastic, solid cardboard and corrugated fibre board. The kind of material or structure adopted depends on the method of perforation, the distance to its destination, the value of the product and the requirement of the market.

1. CFBC Boxes

Corrugated fiberboard is the most widely used material for fruit & vegetable packages because of the following characteristics:

i. Light in weight

ii. Reasonably strong

iii. Flexibility of shape and size

iv. Easy to store and use

v. Good pointing capability

vi .Economical

2. Wooden Boxes

Materials used for manufacture of wooden boxes include natural wood and industrially manufactured wood based sheet materials.

3. Sacks

Sacks are traditionally made of jute fibre or similar natural materials. Most jute sacks are provided in a plain weave. For one tonne transportation of vegetables, materials of 250 grams per square meter or less are used. Natural fibre sacks have in many cases been replaced by sacks made of synthetic materials and paper due to cost factors, appearance, mechanical properties and risk of infestation and spreading of insects. Sacks made of polypropylene of type plain weave are extensively used for root vegetables. The most common fabric weight is 70-80 grams per square meter.

4. Palletisation

Pallets are widely used for the transport of fruit & vegetable packages, in all developed countries.

The advantages of handling packages on pallets are:

i. Labour cost in handling is greatly reduced.

ii. Transport cost is reduced.

iii. Goods are protected and damage reduced.

iv. iv. Mechanized handling is very rapid.

v. v. Through high stacking, storage space can be more efficiently used.

i. Pallets encourage the introduction of standard package sizes.

Packaging films

The packaging industry has become increasingly responsive to the specific gas requirements of fresh produce and is now providing films tailored to the requirements of given types of fresh produce. Films are available for commodities having low, medium and high respiration rates. The oxygen transmission rates of the films are matched to the minimum level of O_2 required for the produce to retain its quality.

Modified atmosphere packaging films

Modified atmosphere packaging (MAP) employs packaging films to manipulate the respiration rates of fresh produce and thereby extend shelf life. MAP makes use of the carbon dioxide produced by respiration and oxygen consumed during the respiration process, for the production of an environment within the package that slows the metabolic activity of the produce. The goal of MAP is to create an equilibrium atmosphere, such that the oxygen concentration is adequately low and the carbon dioxide concentration is adequately high, to be beneficial and not injurious to the produce.

Packaging films such as low density polyethylene, which can be easily sealed and offer good permeability to O_2 and CO_2, are durable at low temperatures and which have good tearing resistance, are appropriate in use for MAP. MAP films can be impregnated with minerals in order to absorb and remove ethylene produced in the storage environment around the bagged produce. Impregnated MAP films are particularly suitable for transporting bulk fresh fruit and vegetables to distant markets or between farmers and consumers at supermarkets and retail outlets.

Produce contained in MAP must be maintained under appropriate temperature conditions and must be properly handled and packaged prior to transport if freshness is to be maintained, shelf life extended and safety assured. Neither low temperature nor MAP can act alone to deliver full value to the consumer, the reason being that both factors work together to slow the metabolism and aging of the produce thereby extending the shelf life and maintaining the quality.

3.3.5 Key considerations when selecting packaging materials suited to fresh produce

• Container dimensions – Containers must be of the appropriate weight and measurements. They can be altered to suit the needs of the handler and the produce item. For example, tomato boxes must be 39cm long and 25cm wide, with 3.5cm raised corners such as triangular corner supports to increase the strength of the carton.

• Ventilation – Fresh-air exchange helps prevent unwanted ripening and the accumulation of odours, and ensures longer shelf life for many perishables. Holes within the packaging facilitate both horizontal and vertical airflow, thereby facilitating cooling of the produce. Temperature management can be difficult if packing materials block ventilation holes

• Ease of handling – The weight and size of boxes must facilitate easy handling.

• Compliance with standard design and marketing demand – The specific packaging requirements of buyers must be taken into account during the selection of packaging materials. Many supermarket chains differentiate themselves from others through unique packing or branding. Chemicals that are banned in certain importing countries may not be used in packaging. In fact, a number of importing countries now stipulate that packaging must be recyclable and must clearly identify the product and its origin so that it can be traced back to its source.

Packaging material design must include holes (5 per cent) for ventilation

ii. Ease of palletisation – cartons are the primary form of outer packaging used for the international export of fruit. Pallets provide a strong base for transporting and storing cartons that weigh up to 1 tonne. The stacking pattern of palletised cartons is dependent on the height of the carton and the positioning of the ventilation holes. Pallets must be constructed from environmentally friendly materials and must comply with the standards of the exporting and importing countries. Effective as of 2005, all packaging material made of wood must be either heat- or chemically-treated to comply with international standards.

iii. **The following basic care must be taken during palletisation:**

- Surface finish – the surface of the package must be smooth in order to prevent damage to the produce
- Easy of cleaning – packaging must be easily cleaned if it is to be re-used

3.3.6 Packaging materials for produce destined for local markets

Woven plastic packaging

• withstands impact;

• provides protection against insects if closely woven;

• is somewhat effective in preventing contamination; and

• does not absorb moisture.

Fibreboard

• provides some protection against insects.

Plastic crates

• withstand impact during transportation;

• can be easily stacked and palletised; and

• offer some protection against contamination.

Jute bags

• provide good protection against impact damage;
• do not absorb moisture;
• are biodegradable; and
• retain produce odour.

Corrugated cardboard boxes

- withstand impact forces and localise the produce;
- if they are waxed, provide protection against moisture and humid environments;
- contribute to prevention of produce contamination; and
- are stackable and can be palletised during transportation.

3.3.7 Packaging materials for produce destined for long-distance and export markets

Bulk bins

Bulk bins (1000 x 1200mm), which are capable of carrying 300kg of fruit, are used for the export of produce items such as oranges for juicing. Bulk bins can be stacked on top of each other and fastened with securing strips. The combined weight of the bins must be less than 900kg.

Cartons

Fruit cartons made from corrugated cardboard, polystyrene and polypropylene are used for the export of fresh produce. The packaging container must comply with standards set by the exporting and importing country. Cartons must be strong enough to bear the weight of the produce, must either be waxed or should not absorb moisture easily and should be adequately ventilated so as to allow horizontal and vertical airflow.

The number of cartons stacked on a pallet is dependent on the size and depth of the cartons. For example, a total of 75 cartons measuring 600 x 400 x 120mm can be stacked on a 2.1m pallet, while 260 cartons measuring 400 x 300 x 70 mm can be accommodated on a pallet stacked to a similar height.

Each carton may contain fruit packaged in small units or secondary packaging units such as fruit wrappers, plastic bags, nettings or punnets. Nets offer the advantage of allowing the fruit to breathe freely. Punnets are generally made of polypropylene or polyethylene and are used for the packaging of small fruits such as plums, apricots and grapes. Some buyers require that grapes be packed in polycot, carry or ‘zip lock’ bags.

3.3.8 Labelling

Labelling helps handlers to keep track of the produce as it moves through the horticultural supply chain. Labelling assists the wholesale agents and retailers in using proper practices. Labels are pre-printed or glued, stamped or stencilled on to the packaging container.

The label must mention the following:

- count, cultivar, class type or size;
- weight;
- producer’s code;
- pack house code;

- name and address of the exporting packer;
- country of origin;
- any special treatment given e.g. SO_2 fumigation or type of approved wax or pesticides used etc.; and
- recommended storage temperature and special handling instructions.

3.3.9 Types of Packages

3.3.9.1.Controlled and Modified Atmospheric Packaging (CAP and MAP)

The normal composition of air is 78% Nitrogen, 21% Oxygen, 0.03% Carbon dioxide and traces of other noble gases. Modified atmosphere packaging is the method for extending the shelf-life of perishable and semi-perishable food products by altering the relative proportions of atmospheric gases that surround the produce. Although the terms Controlled Atmosphere (CA) and Modified Atmosphere (MA) are often used interchangeably a precise difference exists between these two terms.

3.3.9.2 Controlled Atmosphere (CA)

This refers to a storage atmosphere that is different from the normal atmosphere in its composition, wherein the component gases are precisely adjusted to specific concentrations and maintained throughout the storage and distribution of the perishable foods. Controlled atmosphere relies on the continuous measurement of the composition of the storage atmosphere and injection of the appropriate gases or gas mixtures into it, if and when needed. Hence, the system requires sophisticated instruments to monitor the gas levels and is therefore practical only for refrigerated bulk storage or shipment of commodities in large containers.

If the composition of atmosphere in CA system is not closely controlled or if the storage atmosphere is accidentally modified, potential benefit can turn into actual disaster. The degree of susceptibility to injury and the specific symptoms vary, not only between cultivars, but even between growing areas for the same cultivars and between years for a given location. With tomatoes, excessively low O2 or high CO2 prevents proper ripening even after removal of the fruit to air, and CA enhances the danger of chilling injury. The differences between beneficial and harmful concentrations of oxygen and carbon dioxide for each kind of produce are relatively small, so great care must be taken when using these technologies.

3.3.9.3 Modified Atmospheric Packaging (MAP)

Unlike CAPs, there is no means to control precisely the atmospheric components at a specific concentration in MAP once a package has been hermetically sealed.

Modified atmosphere conditions are created inside the packages by the commodity itself and / or by active modification. Commodity generated or passive MA (Modified Atmosphere) is evolved as a consequence of the commodity's respiration. Active modification involves creating a slight vacuum inside the package and replacing it with a desired mixture of gases, so as to establish desired EMA (Equilibrated Modified Atmosphere) quickly composed to a passively generated EMA.

Another active modification technique is the use of carbon dioxide or ethyl absorbers (scavengers) within the package to prevent the build-up of the particular gas within the package. This method is called active packaging. Compounds like hydrated lime, activated charcoal, magnesium oxide are known to absorb carbon dioxide while iron powder is known as a scavenger to carbon dioxide. Potassium permanganate and phenyl methyl silicone can be used to absorb ethylene within the packages. These scavengers can be held in small sachets within the packages or impregnated in the wrappers or into porous materials like vermiculite.

For the actively respiring commodities like fruits and vegetables, the package atmosphere should contain oxygen and carbon dioxide at levels optimum to the particular commodity. In general, MA containing between 2-5% oxygen and 3.8% carbon dioxide have shown to extend the shelf life of a wide variety of fruits and vegetables.

If the shelf life of a commodity at 20-25◦C is one day, then by employing MAP, it will get doubled, whereas refrigeration can extend the shelf life to 3, and refrigeration combined with MAP can increase it to four days. Few types of films are routinely used for MAP. The important ones are polyvinyl chloride, (PVC), polystyrene, (PS), polyethylene (PE) and polypropylene (PP). The recent developments in co-extrusion technology have made it possible to manufacture films with designed transmission rates of oxygen.

3.3.9.4 Vacuum packaging

Vacuum packaging offers an extensive barrier against corrosion, oxidation, moisture, drying out, dirt, attraction of dust by electric charge, ultra violet rays and mechanical damages, fungus growth or perishability etc. This technology has commendable relevance for tropical countries with high atmospheric humidity.

In vacuum packaging, the product to be packed is put in a vacuum bag (made of special, hermetic fills) that is then evacuated in a vacuum chamber and then sealed hermetically in order to provide a total barrier against air and moisture. If some of the product cannot bear the atmospheric pressure due to vacuum inside the package then the packages are flushed with inert gases like Nitrogen and CO_2 after evacuation.

3.3.9.5 Edible Packaging

An edible film or coating is simply defined as a thin continuous layer of edible material formed on, placed on, or between the foods or food components. The package is an integral part of the food, which can be eaten as a part of the whole food product. Selection of material for use in edible packaging is based on its properties to act as barrier to moisture and gases, mechanical strength, physical properties, and resistance to microbial growth. The types of materials used for edible packaging include lipids, proteins and polysaccharides or a combination of any two or all of these. Many lipid compounds, such as animal and vegetable fats, acetoglycerides have been used in the formulation of edible packaging for fresh produces because of their excellent moisture barrier properties. Lipid coatings on fresh fruits and vegetables reduce weight losses due to dehydration during storage by 40-70 per cent. Research and development effort is required to develop edible films and coatings that have good packaging performance besides being economical.

3.3.10 Packing techniques

Packing techniques must ensure that:

• Produce is correctly arranged within the packaging material to reduce the risk of damage;

• Produce is not damaged by wounding during the packing process – for example, by micro-wounding because of nails sticking into the produce, thereby creating an ecological niche for microbial infection; and

• Hygienic conditions are maintained – contaminated hands or contaminated containers may transfer food-borne pathogens to the produce. Fresh produce packers must observe high levels of personal hygiene: gloves can be worn during packing, but should be washed at regular intervals to prevent them from becoming a trap for food-borne pathogens.

Packing must also be done against a tight time schedule to ensure that produce can be moved efficiently through the supply chain.

3.3.11 Procedures to make packages more effective

i. Ventilation of Packages

Reduction of moisture loss from the product is a principal requirement of limited permeability packaging materials. A solution to moisture loss problems from produce appeared with the development and wide distribution of semi permeable plastic films. Airflow through the ventilation holes allows hot fruit or vegetable to slowly cool and avoid the buildup of heat produced by the commodity in respiration. Holes are also important in cooling the fruit when the packages are placed in a cold storage, especially with forced air-cooling. Ventilation holes improve the dispersal of ethylene produced.

ii. Cushioning Materials

The function of cushioning materials is to fix the commodities inside the packages and prevent them from mixing about in relation to each other and the package itself, when there is a vibration or impact. Some cushioning materials can also provide packages with additional stacking strength. The cushioning materials used vary with the commodity and may be made of wrapping papers, fibreboard (single or double wall), moulded paper pulp trays, moulded foam polystyrene trays, moulded plastic trays, foam plastic sheet, plastic bubble pads, fine shredded wood, plastic film liners or bags.

iii. Throughout the entire handling system, packaging can be both an aid and a hindrance to obtaining maximum storage life and quality. Packages need to be vented yet be sturdy enough to prevent collapse. If produce is packed for ease of handling, waxed cartons, wooden crates or rigid plastic containers are preferable to bags or open baskets, since bags and baskets provide no protection to the produce when stacked.

iv. Containers should not be filled either too loosely or too tightly for best results. Loose products may vibrate against others and cause bruising, while over-packing results in compression bruising. Shredded newspaper is inexpensive and a lightweight filler for shipping container

vi. Ethylene absorber sachets placed into containers with ethylene sensitive produce can reduce the rate of ripening of fruits, de-greening of vegetables or floral wilting.

3.4 Handling at whole sale and retail outlet

When handling produce at its destination, the following should be observed

- it is important to avoid rough handling,
- minimize the number of handling steps, and
- maintain the lowest feasible temperature.
- If produce is to be stored before sale, then wholesale and retail markets need clean, well insulated storage rooms.
- it is important to remember not to mix those with different temperature requirements
- or store ethylene sensitive commodities near ethylene generating commodities.
- Stacking of non-uniform containers should be done with care to prevent collapse of weaker packages.
- Before produce is sold to the consumer, the handler may wish to sort for quality, or at least to discard any damaged or decayed produce in order to give the product more market appeal.
- If ripeness or maturity is non-uniform, sorting at destination can provide the seller with a higher price for the better quality produce.
- If the produce handled is a climacteric fruit crop that was harvested before it was ripe (bananas, tomatoes, avocadoes, mangoes), the handler at destination may want to ripen the produce before it is sold to the public. Sometimes commodities such as bananas are left at ambient temperatures and allowed to ripen naturally. Covering the bananas with a plastic sheet will help ripening be more uniform throughout the lot
- Placing a simple air vent (a pipe or a tube of some sort) into the center of the pile of ripening fruit can help reduce overheating during ripening and increase subsequent shelf life.
- The introduction of ethylene gas or ethylene-releasing compounds into a special storage environment (known as a ripening room or cabinet, depending upon size) is a more effective way to ensure uniform ripening.
- Temperatures of the display tables or refrigerated supermarket displays should be suited to the commodity on sale. For example, while peppers and tomatoes look pleasing when displayed with lettuce, peppers and tomatoes are chilling sensitive, while lettuce is not.
- Misting commodities that can tolerate surface water (lettuce, broccoli, green onions) with cool clean water can help maintain a high relative humidity around the product.
- Outdoor marketplaces suffer from a lack of temperature control and high air circulation, which can lead to desiccation of crops, which will be seen as shriveling

and wilting. These marketplaces can often benefit by the increased use of shading and protection from prevailing winds.

Finally, the handler at destination can help reduce losses in the future by maintaining good records of the sources of losses suffered at the wholesale or retail level. Identifying whether losses were due to mechanical damage, decay/disease, immaturity or over-ripeness allows the handler to provide better quality feedback to produce suppliers.

Unloading

A loading dock can ease the work associated with handling horticultural produce at destination. Containers can be transferred more rapidly and with less bending and lifting.

For large trucks, a loading dock 117 to 122 cm high (46 to 48 inches) functions well, while for small trucks or pickups a height of 66 to 81 cm (26 to 32 inches) is recommended.

A simple set of stairs can be constructed to ease the work of loading and unloading produce. Providing hand-trucks or small carts can also ease the work associated with unloading.

Temporary storage temperatures

When produce is held at destination for a short time before marketing, the handler can help maintain quality and reduce losses by storing commodities at their most suitable temperature. However, if the storage period is seven days or less, relative humidity is maintained between 85 and 95%, and the ethylene level is kept below 1 ppm, by ventilating or using a scrubber.

Sorting/repacking

Some produce may require washing, trimming, bunching or sorting at the wholesale or retail market level. The layout of the work station used for handling produce at destination should be organized to minimize non-productive movement. In the illustration below, a dump table is located next to a sink for washing produce, and the drain board is positioned directly next to the sink. Once produce has dried, cartons can be packed and placed onto a cart located right next to the repacking table. With this layout, a single operator could easily perform all the handling steps or several handlers could work side by side.

Some produce may have to be repacked by the wholesaler or retailer due to changes in quality or uneven ripening. The tomato sorting table illustrated below has work stations for up to five who select ripes, pinks or breakers and allow the green tomatoes to run off to the end of the line. Rejects (culls) are placed in pails under the table.

Ripening

Ripening is the process by which fruits attain their desirable flavor, color and textural properties. **Climacteric fruits can ripen off the plant** once they have reached physiological maturity.

Climacteric fruits include apples, avocado, banana, blueberries, breadfruit, cherimoya, durian, feijoa, fig, guava, kiwifruit, mango, muskmelon, papaya, passion fruit, pears, persimmon, plantain, quince, sapodilla, sapote, soursop, stone fruits (apricots, nectarines, peaches, plums) and tomato. Some of these these fruits if harvested "mature-green", can be ripened after harvest and short term storage. Pears and bananas are unusual in that they develop the best flavor and texture characteristics when harvested mature-green and ripened off the tree. Avocadoes do not ripen on the tree.

Some climacteric fruits give off large quantities of ethylene during ripening. These include apples, apricots, avocadoes, cantaloupe, kiwifruit, nectarines, peaches, pears, plums and passion fruit. A small dose of ethylene gas will stimulate other climacteric fruits to begin the ripening process. A few climacteric fruits, such as muskmelons, will not increase in sugar content during ripening, but will soften.

Non-climacteric fruits must ripen on the plant if you want a fully ripe fruit, since once they have been harvested, no further ripening will occur. Flavor and texture will be of low quality if fruits are picked before fully ripe. Some **non-climacteric** fruits include berries, cherries, citrus fruits (lemons, limes, oranges, grapefruits, mandarins, tangerines), cucumber, dates, eggplant, grapes, lychee, okra, peas, peppers, pineapple, pomegranates, strawberry, summer squash, tamarillo and watermelon.

Non-climacteric fruits will not respond to attempts to ripen them with ethylene gas. A partially red strawberry, for example, will not develop any more color or sweetness after being picked, and will deteriorate faster if exposed to ethylene. Watermelons develop most of their sweetness during the week before they reach full maturity, making early harvest very undesirable.

Sometimes ripening commodities before sale at the wholesale or retail level will improve their value. Ripening rooms are often used for tomatoes, citrus fruits and bananas. The use of diluted ethylene gas mixtures is safer than using pure ethylene which is explosive and flammable at concentrations of 3% or higher. For tomatoes, technical grade ethylene gas is introduced into the room at a concentration of about 100 ppm for about 48 hours. Approximately 0.25 cubic feet/hr of ethylene gas is required for each 1000 cubic feet of ripening room volume. A small fan can be used to ensure a uniform continuous flow of ethylene into and through the room. Forced-air ripening is increasingly being used to provide more uniform temperatures and ethylene concentrations throughout the ripening room. Small-scale wholesalers and retailers can ripen fruits in bins or large cartons by placing a small quantity of ethylene-generating produce such as ripe bananas in with the produce to be ripened. Cover the bin or carton with a plastic sheet for 24 hours, then remove the plastic cover. A simple way to ripen fruits at home in small amounts is to use a ripening bowl. Fruits that require ripening should be placed into the bowl with a ripe apple or ripe banana (or any other high ethylene-generating product). Using this method, ripening will take from one to four days. Home ripening is also possible using another, extremely low-tech practice place fruits to be ripened into a paper bag with a ripe piece of fruit, close loosely and check in a few days.

Display

This wooden display table is designed to be used for commodities such as cruciferous crops or leafy green vegetables that tolerate cooling with ice. The table can be used in the horizontal position or as a tilted display.

Four to five lbs of crushed ice per square foot of display space are required for cooling per day. A catch pail should be provided for melt water. To minimize ice needs, the display tray should be insulated and kept out of the direct sun. When displaying horticultural crops, single or double layers of produce are most likely to protect the commodities from compression damage and over-handling by the consumers.

High relative humidity can be maintained during display by misting leafy vegetables and water tolerant crops with clean, cold water. A simple sprinkler device can be constructed by perforating a pipe with tiny holes and connecting it to a hose. If this display is used outdoors, shade should be provided. Displays and storage areas must be cleaned and sanitized on a regular basis. Trimmings, waste, and bruised product remaining in displays are unsightly and can be sources of decay, odor and ethylene.

7.0 Conclusion

If produce is to be stored, it is important to begin with a high quality product Produce can be stored for both short-term and long-term purposes. Short-term storage is mainly used to provide flexibility in marketing (e.g. when awaiting transport), or because buyers are not immediately available. The lot of produce must not contain damaged or diseased units, and containers must be well ventilated and strong enough to withstand stacking. In general, proper storage practices include temperature control, relative humidity control, air circulation and maintenance of space between containers for adequate ventilation, and avoiding incompatible product mixes. Commodities stored together should be capable of tolerating the same temperature, relative humidity and level of ethylene in the storage environment. The choice of cooling methods is dependent on a number of considerations: Nature of the produce, Package design, Product flow capacity, Economic factors and Social factors. Factors that may compromise quality during transportation; Are Mechanical damage, Overheating and Build up of gases in the transport system Packaging is a coordinated system of preparing goods for safe, secure, efficient, and effective handling, transport, distribution, storage, retailing, consumption and recovery, reuse or disposal combined with maximising consumer vale and hence profit.

8.0 Summary

In this unit we have studied the conditions of crop storage, controlled atmosphere store, cooling in storage, factors that may reduce quality of produce during storage, hygiene in transportation, Packaging for Fruits and Vegetables and how the new technology and applications used to bring fresh, safe, nutritious produce to the consumer were explained. It explains Modified Atmosphere Packaging (MAP) and its use in packaging fruits and vegetables; it includes variations and advances on MAP such as high vapor-permeable films, and demonstrates modelling techniques to assist in the prediction and selection of packaging type and materials for packaging

6.0Tutor Marked Assignment (TMA)

vii. Explain the conditions of storage of crop produce
viii. State the importance of packaging
ix. Describe the important measures to be observed when handling produce at its destination
x. Describe the factors that may compromise quality during transportation
xi. Explain the major considerations when selecting packaging materials suited to fresh produce
xii. State the Importance of pre-cooling in the storage of crop produce
xiii. Describe packaging materials for local markets

xiv. Describe packaging materials for produce destine for foreign markets

xv. Describe handling practices at whole sale and retail outlets

7.0 References and Further Reading

1. A.A. Kader (2002). Postharvest Technology of Horticultural Crops, third edition. University of California , ANR Publication 3311
2. Barkai-Golan, R. and Phillips, D.J. (1991) Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.
3. Carol Thomas (2005) Post Harvest Handling of produce. News Letter of Inter American Institute for Cooperation in Agriculture (IICA)
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
6. Jelle Hayma. 2003 The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
7. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. p.455-469
8. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
9. Kader A. A. (1999). Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
10. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation.
11. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
12. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
13. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa Wold Bank Report No. 60371-AFR. April 2011
14. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257, in:

15. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California , Division of Agriculture and Natural Resources, UC Bulletin 1914.
16. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
17. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
18. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
19. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
20. Zinash Delebo OSUNDE (2008); Minimizing Postharvest Losses in Yam (*Dioscorea spp.*) Treatments and Techniques; Using Food Science and Technology to Improve Nutrition and Promote National Development, International Union of Food Science & Technology (2008)
21. http://postharvest.ucdavis.edu
22. http://www.fao.org/docrep/
23. http://www.crcpress.com/product
24. http://www.actahort.org/books
25. http://sciencedirect.com/science/journal
26. http://www.stewartspostharvest.com

UNIT 5: OPERATIONAL EQUIPMENTS/STRUCTURES OF STORAGE AND PRESERVATION

Table of contents

1.0 Introduction

The storage structures used depend on the construction material available, amount of produce to be stored, the type of produce, prevailing climatic condition of the area, purpose of storage and the resources of the farmer, in particular the availability of labour and capital.

2.0 Objectives

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

- Identify and describe the different kinds of storage structures commonly used in your locality
- Recommend the most appropriate crop produce storage structure considering the environmental factors
- Recommend the most appropriate structure for the storage of cereals, tubers, roots bulbs, vegetables and fruits

3.0 Equipment for produce storage and preservation

3.1 Yam Storage Structures

Yam storage structures from the different ecological zones of Nigeria. The storage structures used depend on the construction material available, amount of tuber produced, prevailing climatic condition of the area, purpose of yam tuber storage, socio-cultural aspects of storage and the resources of the farmer, in particular the availability of labour and capital. In the humid forest zone yam is stored in a yam barn which is the principal traditional yam storage structure in the major producing areas. Barns in the humid forest zone are usually located under the shade and constructed so as to facilitate adequate ventilation while protecting tubers from flooding, direct sunlight and insect attack. There are several designs, but they all consist of a vertical wooden framework to which the tubers are individually attached [fig.1]. Tubers are tied to a rope and hung on horizontal poles 1-2 m high (Figure 1); barns up to 4 m high are not uncommon. Depending on the quantity of tuber to be stored, frames can be 2 m or more in length. The ropes are usually fibrous; in south-eastern Nigeria they are made from the raffia obtained from the top part of the palm wine tree. Many farmers have permanent barns that need annual maintenance during the year’s harvest. In these situations, the vertical posts are often made from growing trees which are trimmed periodically. Palm fronds and other materials are used to provide shade. The vegetative growth on the vertical trees also shades the tubers from excessive solar heat and rain

Figure 1.3.5 Typical yam barn in the humid forest zone of Nigeria (individual yams tied to live poles)

The yam barn in the Guinea Savannah zone is constructed from guinea corn stalk, sticks, grass and yam vines (fig.2). The yams are heaped at different positions in the barn. Such barns are constructed every year and are situated near the house under a tree to protect the tuber from excessive heat. At the end of the storage period the barn is burnt down and in December/January a new structure is built for the next harvest. Unlike the humid forest where it is important that the yams are separated to avoid rotting, in drier areas such as Niger State the yams can be stacked into piles in the barn.


Figure.2.3.5 yam barn in guinea savanna

At the onset of the rainy season the yams are transferred to a mud hut or guinea corn storage rhombu to protect them from the rain. Another yam storage structure found in the savanna region is the yam house or yam crib. “Yam houses” have thatched roofs and wooden floors, and the walls are sometimes made simply out of bamboo. They are raised well off the ground with rat guards fitted to the pillars. Yam tubers are stacked carefully inside the crib (Figure 3). Yam is also stored underground in trench or clamp silos. In both methods a pit is excavated and lined with straw or similar material. The tubers are then stored on the layer of straw either horizontally on top of each other or with the tip vertically downwards beside each other. The yams are then covered with straw or similar materials; in some cases a layer of earth is also added.

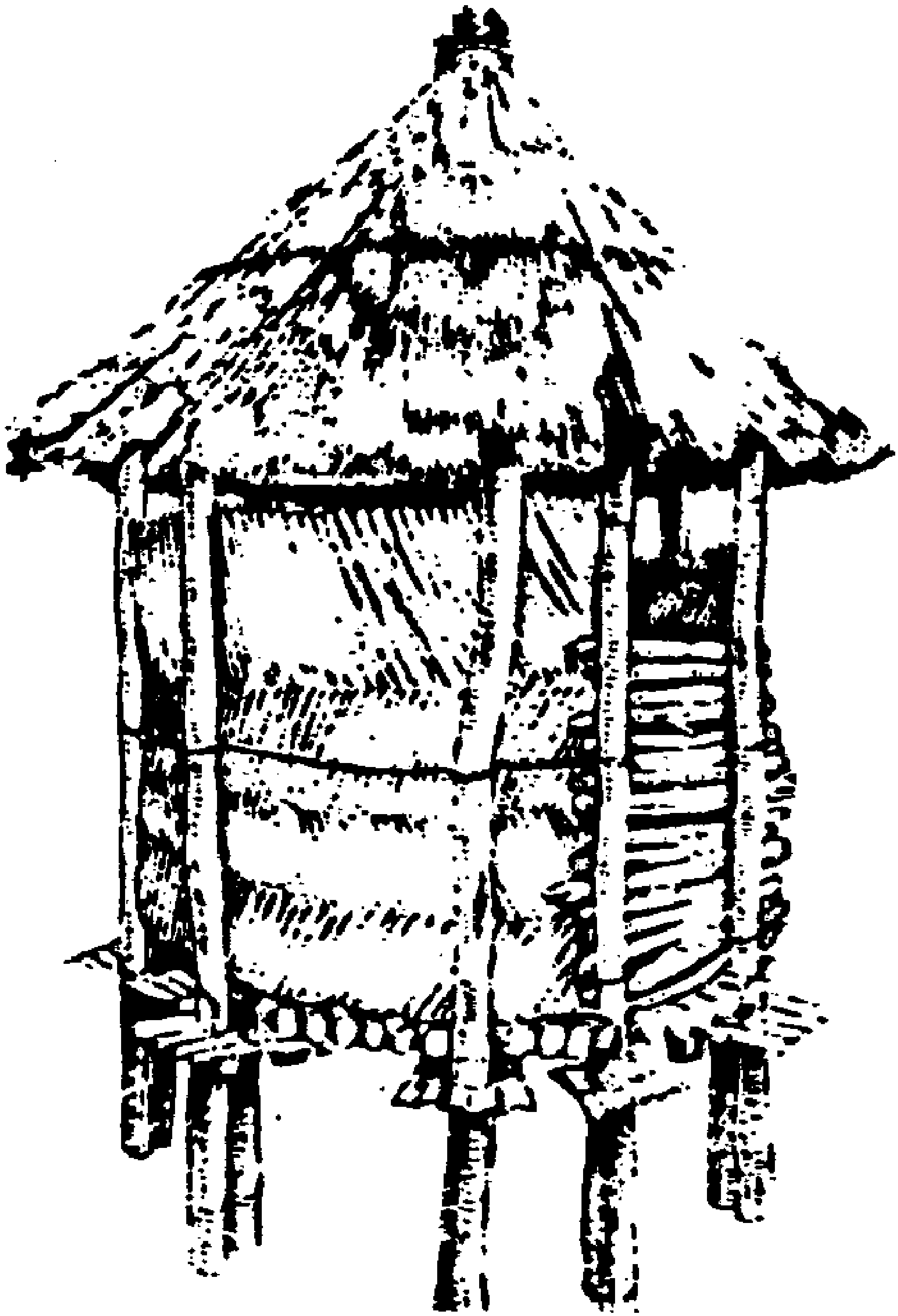


Figure 3.3.5 The yam house crib in the Guinea Savanna zone

3.2Grain storage structures

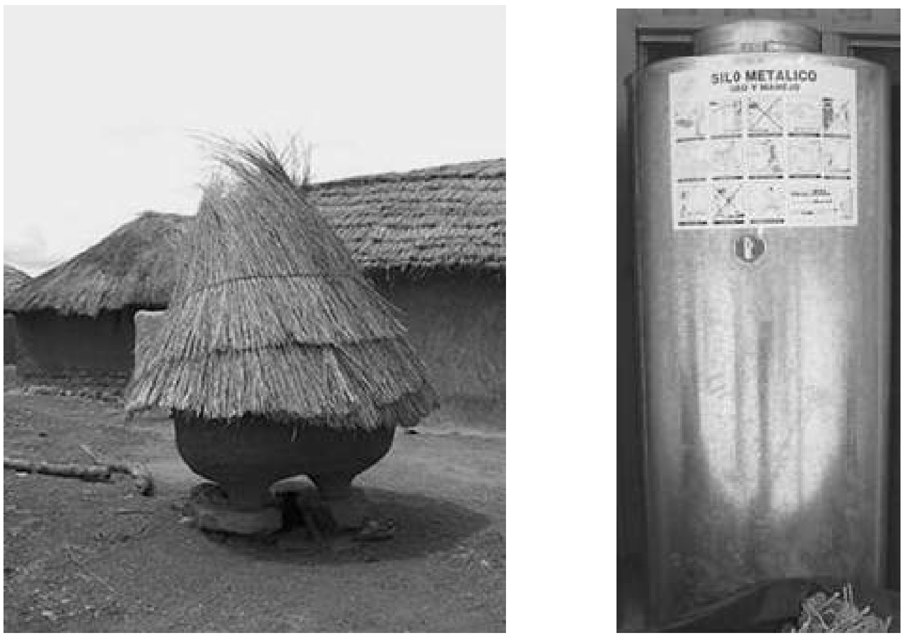
A variety of different storage structures are available according to scale of operation and may either is open to air exchange or airtight (hermetic). Stores offer shelter to the grain, and in addition, hermetic stores by themselves also prevent pest damage. Grains can be stored in sacks of various types on both a small and large scale. For medium- or long-term storage, hermetic sacks may be used when benefits outweigh costs. In other situations, traditional mud stores (as well as more modern plastic or metal silos) may significantly reduce the Post Harvest Losses of smallholders. Such stores may be hermetic or at least sufficiently sealed to prevent pest access to grain.

Adoption of an appropriate and effective method of grain storage can significantly improve the quality and quantity of grain at outturn.

One approach to reducing Post Harvest Losses during storage is either by modifying existing store types so that they perform better or by introducing existing traditional but more effective store types to those communities that *do not already use them* (for example, mud silos). Mud silos (Figure 4.3.5) they offer potential for the better storage of food grains than more open store types can offer, as they are well sealed. Survey work by Opportunity Industrialization Centre, Tamale, has demonstrated that Post Harvest Losses for grain stored in them remain low regardless of whether the crop was treated with a grain storage pest. Modified farm stores can provide solutions to long-standing storage problems in Africa and elsewhere. While grain storage structures help protect against crop losses from insects, rodents, moulds, theft, and fire, traditional designs are not always effective, and building them is difficult for poor communities where the hardwood supply is limited due to deforestation.

FIGURE 4.3. 5 Sealed stores—mud silo (A) and metal silo (B)

A. **B.**



Metal silos clearly do offer continuing opportunities for the reduction of Post Harvest Losses in Sub-Saharan Africa .The main technical constraints for farmers using metal silos are the need to have their grain dry before storage and the need to undertake phosphine fumigation against pest infestation.

Bags and other storage structures (Figure 5.3.5) made of plastic have the advantage that they can be made airtight (hermetic). Under such conditions, biodeterioration can be slowed. One such method currently under extensive promotion is the use of “triple bagging” for cowpea storage, although it could be adapted for grains. The triple-bagging technique was developed as an effective hermetic storage method in Cameroon using two inner bags made of 80 micron polyethylene and one outer, more durable bag to help protect against damage. Well-dried cowpea fills the first bag, which is tied shut securely using string. The first bag is placed within a second bag, and this is closed securely. A third bag is used to enclose the first two and to protect against damage. Clear plastic bags are recommended so that the cowpea can be inspected easily for any signs of insect attack. It is also recommended that the bags should remain sealed for at least two months after they are filled, and after they are opened, they should be resealed quickly to prevent entry of pests. The bags must be kept safe from rodents that might make holes in them and so break the seal.

FIGURE 5.3.5. IRRI super bag (the gas- and moisture proof liner)

Plastic drums (fig.6.3.5) of all sorts, including water tanks, can be sealed and used as effective hermetic grain stores

Figure 6.3.5 plastic granary

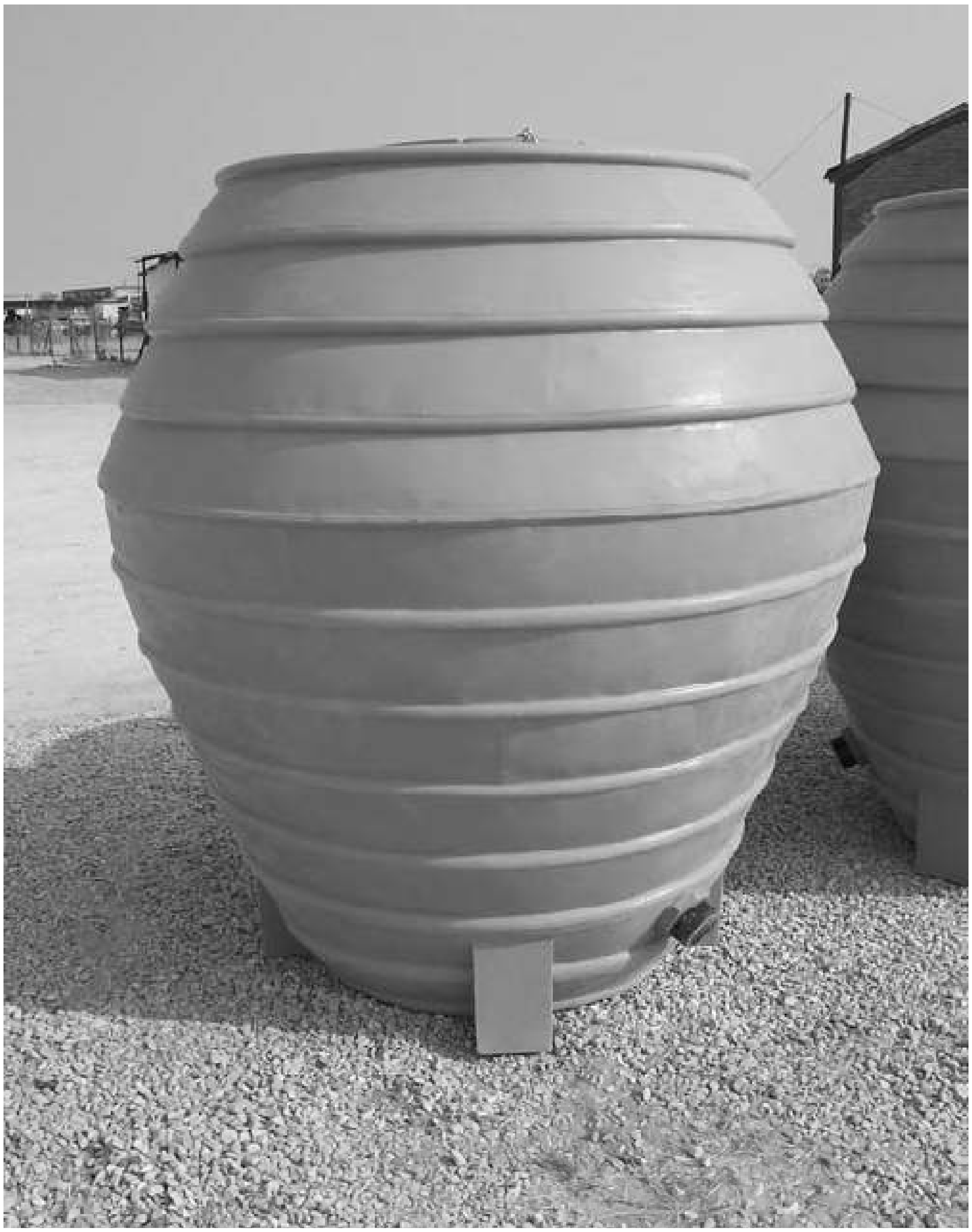


FIGURE 7.3.5 the traditional mopane wood model

4.0 Conclusion

The storage structures used depend on the construction material available, amount of tuber produced, prevailing climatic condition of the area, purpose of yam tuber storage, socio-cultural aspects of storage and the resources of the farmer, in particular the availability of labour and capital. In the humid forest zone yam is stored in a yam barn which is the principal traditional yam storage structure in the major producing areas. Stores offer shelter to the grain, and in addition, hermetic stores by themselves also prevent pest damage. Grains can be stored in sacks of various types on both a small and large scale. For medium- or long-term storage, hermetic sacks may be used when benefits outweigh costs. In other situations, traditional mud stores (as well as more modern plastic or metal silos) may significantly reduce the Post Harvest Losses of smallholders. Such stores may be hermetic or at least sufficiently sealed to prevent pest access to grain.

5.0 Summary

Grain storage structures help protect against crop losses from insects, rodents, moulds, theft, and fire, traditional designs are not always effective, and building them is difficult for poor communities where the hardwood supply is limited due to deforestation.

9.0 Tutor Marked Assignment (TMA)

- Describe the yam barn
- Describe the different types of structures used in storing cereals crops

7.0 References and Further Reading

1. A.A. Kader (2002). Postharvest Technology of Horticultural Crops, third edition. University of California , ANR Publication 3311
2. Barkai-Golan, R. and Phillips, D.J. (1991) Postharvest treatments of fresh fruits and vegetables for decay control. Plant Disease 75:1085-1089.
3. Carol Thomas (2005) Post Harvest Handling of produce. News Letter of Inter American Institute for Cooperation in Agriculture (IICA)
4. Delate, K. et al. (1990). Controlled atmosphere treatments for control of sweet potato weevil in stored tropical sweet potatoes. Journal of Economic Entomology 83:461-465.
5. Harris, Kenton L. and Carl J. Lindblad, eds. (1976) Postharvest Grain Loss Assessment Methods - A Manual of Methods for the Evaluation of Postharvest Losses American Association of Cereals Chemists, 1976
6. H. Arnold Bruns (2009); A Survey of Factors Involved in Crop Maturity. Agronomy Journal Volume 101, Issue 1 • 2009
7. Jelle Hayma. 2003 The storage of tropical agricultural products; Agrodok 31 Agromisa Foundation, Wageningen, 2003
8. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. p.455-469
9. Kader, A. A. (1983). Postharvest Quality Maintenance of Fruits and Vegetables in Developing Countries. In: Lieberman, M., Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469.
10. Kader A. A. (1999). Fruit ripening and quality relationship. Acta Horta. 485, ISHS 1999
11. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation. P.455-469
12. Lieberman, M., (1983) Post-Harvest Physiology and Crop Preservation. Plenum Publishing Corporation.
13. Lisa Kitinoja and Adel A. Kader 2003. Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (4th Edition) University of California, Davis
14. McGregor, B.M. (1989) Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668.
15. MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa

Wold Bank Report No. 60371-AFR. April 2011

16. Mitcham, E.J., F.G. Mitchell, M.L. Arpaia, and A.A. Kader. (2002) Postharvest Treatments for insect control. p. 251-257
17. Moline, H.E. (Ed). (1984) Postharvest Pathology of Fruits and Vegetables. University of California, Division of Agriculture and Natural Resources, UC Bulletin 1914.
18. Paull, R. F and Chen, N. J. 2010. Fruit softening during ripening-causes and regulations. Acta Hort.864:259-266
19. Streif. J. D. Kittemann, D. A. Neuwald, R and others. 2010. Pre and Post harvest management of fruit quality, ripening and senescence. Acta Hort.877:55-68
20. Thompson, J.F. and Spinoglio, M. (1994) Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center , University of California , Davis .
21. Valero, D and Serrano. M. 2010 Postharvest biology and Technology for preservation of fruit quality. CRC Press, Boca Raton, FL. USA
22. Zinash Delebo OSUNDE (2008); Minimizing Postharvest Losses in Yam (*Dioscorea spp.*) Treatments and Techniques; Using Food Science and Technology to Improve Nutrition and Promote National Development, International Union of Food Science & Technology (2008)
23. http://postharvest.ucdavis.edu
24. http://www.fao.org/docrep/
25. http://www.crcpress.com/product
26. http://www.actahort.org/books
27. http://sciencedirect.com/science/journal
28. http://www.stewartspostharvest.com