UNIT 2 AN OVERVIEW OF FOOD PHYSIOLOGY

Structure

2.0 OBJECTIVES

After going through this unit, you should be able to:

- know the different stages of growth in the life of fruit;
- understand the physiological changes in fruits and vegetables that take place after harvest;
- tell how senescence can be delayed; and
- mention the structural and compositional changes that take place after harvest.

2.1 INTRODUCTION

Fruits and vegetables are living tissues and remain alive even after harvest. They undergo considerable morphological and bio-chemical changes during growth and following harvest. The visual changes in colour are most prominent indicator of ripening. Many of the quality parameters of harvested produce are affected by pre-harvest factors starting from planting, planting density, irrigation and hormonal treatment. To obtain a produce with good quality all these factors must be controlled.

2.2 MORPHOLOGICAL CHARACTERISTICS

The life of fruit and vegetable crops can be divided into three major physiological stages following germination- growth, maturation and senescence. Growth involves cell division and subsequent cell enlargement, which accounts for final size of the commodity. Maturation usually commences before growth ceases. Growth and maturation are often collectively referred to as development phase. Senescence is defined as the period when anabolic (synthetic) bio-chemical processes give way to catabolic (degradative) processes, leading to ageing and finally death of the tissue. Ripening is considered to begin during the later stages of maturation and to be the first stage of senescence. Development and maturation of fruit are completed only when it is attached to the plant, but ripening and senescence may proceed on or off the plant. But in many plants, a growth after harvest has been observed which is considered undesirable. Elongation and toughening in asparagus, toughening in beans, sprouting in potato and onions are the examples of such growth that occurs after harvest.

Growth and Development

Many tiny individual cells make up the plant body. Each cell consists of living system [protoplasm] and usually a cell wall. The protoplasm is the most significant part of the plant. It is in fact a factory, which manufactures the products of the plant, including the walls of the cell themselves. It is composed of water, salts, sugars, proteins, fats, enzymes, vitamins, growth regulators and a complex of other materials. All of this is organised, through a special portion of the protoplasm [nucleus], into a living unit. As the plants grow and develop, individual cells divide and differentiate into particular kinds of cells and groups of cells, called tissues and organs performing special functions. This addition of cells and the increase in biomass is called growth. An essential organ of a plant is fruit, which develops from another organ of the plant called flower.

Development of fruit and seed

The flower is a group of specialized leaves concerned with the development of structures, which lead to sexual production. A flower consists of four parts:

i) an outer whorl of sepals, usually green, collectively known as the calyx;
ii) petals, usually coloured, which together are called the corolla;
iii) stamens, which produce the pollen grains and male germ cells; and
iv) the pistil, which consists of one or more sections [carpels] bearing the female germ cell and later the seed.

The flower parts are mounted on a portion of the stem known as receptacle. During the formation and development of flowers of any part of the plant, growth regulators play an important role.

A fruit develops from the ovary of pistil. It may consist of a single carpel, as in cherry or of several carpels, as in tomato. Also other parts of the plant may be associated with the fruit, as the enlarged receptacle of the strawberry, the sepals of mulberry and the stem of the pineapple. Attached to the inner edges of the carpel and enclosed within them are the parts (ovules), which develop into seeds.

Initiation of fruit development

Male cells [gametes] from the pollen grains are transferred to the tip (stigma) of the pistil and grow down (through the style) to fertilize the female cells, which are formed in the ovules enclosed in the ovary. The process by which the pollen grains are transferred to the stigma of pistil is called pollination and the process of the fusion of male and female cells (gametes) is called fertilization. The fertilized cell called zygote further grows, divides, differentiates and develops into a new plant (embryo) enclosed in the seed coats. Later, the ovary develops into a fruit. Therefore, the fruit is a matured or ripened ovary. All these processes are carried through the influence of certain growth regulatory compounds called plant-hormones.

Physiology of growth and development

Carbohydrates, which are essential to both plant and animal life are produced in the leaves in a process known as photosynthesis, in which the green colour pigment of the plant (chlorophyll) utilizes light energy to form simple carbohydrate materials (as sugars) from water and carbon dioxide of the atmosphere.

$$6\ CO_2 + 6\ H_2O + 673{,}000\ \text{Cal} \leftrightarrow C_6H_{12}O_6 + 6\ O_2$$

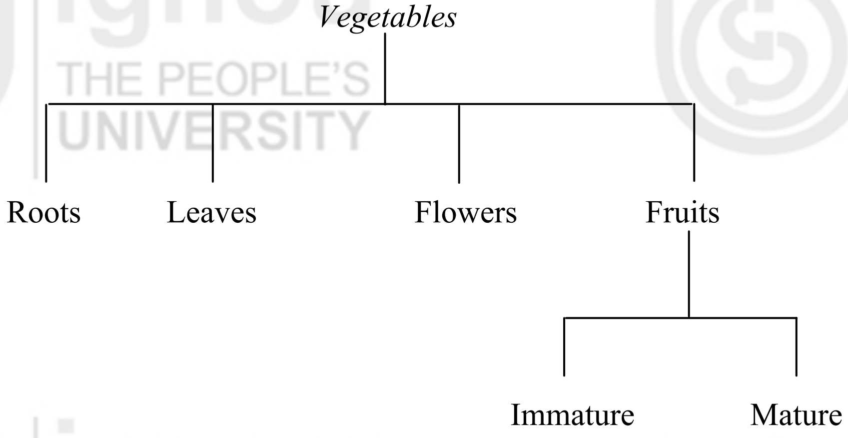
Carbohydrates are moved from the leaves to other parts of the plant. The most important tissues involved in translocation are the xylem and phloem. It is believed that the carbohydrates travel through phloem, while water and minerals travel mainly through xylem.

Food may be stored in various storage organs, such as roots, tubers, rhyzomes, bulbs, corms, fruits and seeds. Storage may occur at different seasons of the year and may in some plants be controlled by the length of the day, the length of the night period and the day & night temperatures. In many plants that live for more than one season (perennials), accumulation in the underground storage organs takes place at a rapid rate in the fall of the year.

Fruits and Vegetables

Fresh fruits, as well as fresh vegetables are essential components of human diet. Both contain a number of nutritionally important compounds, such as vitamins, which cannot be synthesized by the human body; vitamin C is the most important essential nutritive substance found mainly in fruits and vegetables.

The fruits are used as a table commodity whereas the vegetables are usually cooked and then used as food. Some of the vegetables are “fruit-vegetables” and most of the vegetables are the other vegetative organs of the plant that include root, stem, flower, shoot, leaves and associated parts. On the basis of the parts of plants used as food, the vegetables are classified in the following groups:



Similarly, depending on the parts of the ovary wall [pericarp-epicarp, mesocarp and endocarp] developing into flesy and succulent organs of the fruits are classified as under:

Fruits

Drupe | Berry | Pepo | Hesperidum | Pome | Aggregate type

2.3 POST-HARVEST PHYSIOLOGY OF FRUITS AND VEGETABLES

Fruits and vegetables are highly perishable commodities with active metabolism during the post-harvest period. Proper handling plays an important role in increasing food availability. On removal from the parent plant, vegetative parts, such as fruits, roots, stems etc are deprived of their normal supply of minerals, water, and also in some instances, simple organic molecules [e.g. sugars, hormones] that normally would be translocated from other parts of the plant. Innumerable physiological and bio-chemical processes are initiated and continued in the edible plant tissues at the time of harvest. Although the photosynthetic activity is negligible, most tissues remain capable of transforming many of the constituents already present in them. The diversity of metabolic shifts, which are specific to a given commodity [and often variety] are manifest in events such as 'rotting', 'ripening', 'sprouting', 'scald', 'brown core', 'hard core', 'toughening', and 'yellowing'.

The kind and intensity of physiological activity in detached plants determines their storage longevity. Some plant parts, such as seeds, fleshy roots, tubers, bulbs are morphologically and physiologically adapted to maintain the tissue in a dormant state until environmental conditions are favourable for germination or growth. Metabolic activity, though depressed, is not completely halted in such tissues. Fleshy fruits are unusual in that maturation is followed by a ripening process, which is associated with the development of optimal eating quality.

The diversified visible physiological changes, like sprouting, browning, toughening etc are desirable in some commodities and undesirable in others in relation to the eating quality. Almost all such changes are observed during a most important physiological process called ripening.

Physiology of Ripening

The term "ripening" is generally referred to the physical and bio-chemical changes taking place in the fruits after the cessation of growth till the onset of senescence and decay. The ripening process is dependent upon maturity, since a given stage of development must be attained before ripening proceeds. The process of ripening continues while the fruit is on the tree, but the damage caused by the birds, insects etc makes it uneconomical to allow the fruits to ripen on the tree. Hence, the fruits are usually harvested at the horticulturally mature stage. Fruits being living entities continue to carry on the normal physiological processes resulting in the ripening and finally decay or death of the fruit even after they are separated from the parent plant/tree. Most of the fruits show the ripening changes after harvest with a few exceptions like grapes, which are to be ripened only on the vine, as they do not ripen well after harvest. Since the changes taking place in a fruit during ripening greatly influence the eating quality and the monetary value of the commodity depends on it, a detailed knowledge of the physiology and biochemistry of ripening is desirable for the successful storage and marketability of fruits.

Changes during Ripening of Fruits

Important changes occurring in the fruits during ripening include – 1) Respiration, 2) Transpiration, 3) Carbohydrates, 4) Texture, 5) Flavour, 6) Pigments, 7) Organic acids, 8) Nitrogenous compounds, 9) Tannins, and 10) Enzyme activity.

1. Respiration

Fruits and vegetables of different species differ as to the nature and the rate of the changes taking place but most of them share a respiratory pattern known as “the climacteric”. In some fruits, it has been observed that the respiration rate increases with the ripening to a maximum level called as ‘Climacteric’ peak which is followed by a steady decline in respiration rate, often called senescence. The fruit attains the eating ripe stage at the climacteric peak or sometime after the peak, depending on the species and to some extent temperature and composition of the atmosphere in which the commodity is stored. All other fruits showing no such respiratory pattern are called non-climacteric. In citrus fruits [oranges and lemons], the maturation and ripening progress slowly and the respiratory activity tends to decline following harvesting of commercially mature fruits.

Another important criterion for distinguishing a ‘Climacteric fruit’ from a ‘non-climacteric fruit’ is the response to ethylene application. It is well known that ethylene has an enhancing effect on fruit respiration. Biole (1954) showed that a non-climacteric fruit would react to ethylene treatment at any stage of its preharvest or postharvest life, whereas a climacteric fruit will exhibit a respiratory response only if ethylene is available during the pre-climacteric stage, and becomes insensitive to ethylene treatment after the onset of the climacteric rise.

There is a fairly consistent relationship between storage type of fleshy plant tissues and respiration, e.g. peas with a high respiration rate [50 mg CO_2/kg/hr] have a short storage life [1 week at 5°C], while turnips with low respiration rate [6 mg CO_2/kg/hr] have a long storage life [16-20 weeks at 5°C]. The shelf life of a given commodity can be greatly extended by placing it in an environment, which retards the rate of respiration. In other words, the environment modification by refrigeration and carbon dioxide/oxygen (CO_2/O_2) conc. controlled atmosphere will provide a direct effect on the determination of shelf life of the commodities.

Respiratory quotient

From measurements of CO_2 and O_2, it is possible to evaluate the nature of respiratory process. The ratio of CO_2 to O_2 is termed the respiratory quotient [RQ]. This is useful in deducing the nature of the substrate used in respiration, completeness of the respiratory reaction and degree of anaerobic or aerobic process.

2. *Transpiration*

When the fruit is picked and severed from the plant, water no longer flows into the fruit, although the loss of water continues. This process of loss of water in vapour form is known as transpiration. By the time the fruit loses 5% of its original weight, it appears shriveled enough to lose its eye appeal as well as the eating quality. The fruit becomes unattractive because of wrinkled appearance. Hence, this loss of water due to transpiration should be checked in order to maintain its marketability. Judicious application of wax emulsion or other skin coating or pre-packaging with thin paper or cling films could successfully reduce such water losses. On the other hand, in some fruits during ripening, the water content of the pulp increases and the peel decreases, as in the case of banana, which makes the fruit better in eating quality.

2.4 STRUCTURAL CHANGES DURING GROWTH AND RIPENING

A number of changes occur in fruits during ripening. Softening of tissue during ripening is attributed to the changes in cell wall thickness, permeability of plasmalemma, and amount of intercellular spaces. The change in colour of ripened fruit is due to transformation of chloroplast to chromoplast. Although the structure of mitochondria is maintained during growth and ripening, it may degrade in overripe stage. Cuticle deposition increases continuously during ripening but the epidermal hairs either reduce in number or disappear completely.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the different phases of growth in the life of a fruit?

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2. How does softening of tissues occur in fruits during ripening?

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3. Why colour of a commodity changes during ripening?

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4. What is senescence?

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2.5 COMPOSITIONAL CHANGES DURING GROWTH AND RIPENING

Carbohydrate

Sugars are important for pleasing fruit flavour (sugar acid ratio), attractive colour and texture. As the ripening starts these sugars undergo metabolic transformation both quantitatively and qualitatively. Most of the soluble carbohydrates are metabolized completely as the fruit ripens. Pectic substances and cellulose are the reserve carbohydrates that also serve as potential sources of acids, sugars and other respiratory substances during ripening.

In the process of ripening many changes occur in the carbohydrates fraction of fruit during the climacteric and senescence. Green or raw fruit usually contains starch in abundance, but is short in soluble sugars that provides sweetness to it. During ripening, the starch is enzymatically [hydrolysis by alpha- and beta-amylases] converted into sugars. Thus, the major bulk of carbohydrate fraction of a fully ripened fruit consists of sugars. The sugars commonly found in fruits are glucose and fructose [invert sugars] and sucrose.

Organic Acids

The organic acids are among the major cellular constituent undergoing changes during ripening. In most of the fruits there is a considerable decrease in the acidity of fruits during ripening.

The sourness of fruits is due to the presence of organic acids like citric, malic, succinic, tartaric, oxalic etc. These acids usually decide the quality of fruits as the blending of sugar and acids render the fruits tasty, besides flavour. Though these organic acids are present in varying amounts in raw or unripe fruits, but the concentration considerably changes as the fruits ripen. In fruits like oranges, the acids are converted enzymatically into sugars rendering them sweet as they ripen, whereas there is no change in lemons. So they remain sour till they start decaying. But, in some fruits like mangoes, there is a considerable decrease in acidity when the fruits fully ripen. This is probably due to the utilization of these acids in respiration through Kreb's Cycle. Generally, in fruits the total acidity shows a decrease with the increase in ripeness of the fruits.

Amino Acids and Proteins

A major turnover of amino acids in mango takes place during ripening, whereas in carombola it continuously declines. Small increases in protein content were also observed in mango, tomato and avocado.

The nitrogen content of fruit is due to proteins forming insoluble fraction and the soluble fraction comprised of amino acids. The total nitrogen content of fruits at the early stages is high, but with the advancement in growth, shows gradual decrease. This is probably due to the increase in other constituents like water, starch, sugar, organic acids etc. During ripening, the total nitrogen may show a further decrease in some cases.

Lipids

Phospholipids occur in the cytoplasm and in many structural units of plant tissues. They are physiologically more important than neutral lipids in storage organs. Considerable increases in the level of total lipids and fatty acids have been observed in ripening mango in contrast to many fruits and vegetables. However in fatty fruits of avocado the oil composition during maturation remains more or less constant.

Chlorophyll

Disappearance of green colour marks the initiation of ripening in most of the fruits. Chlorophyll content of ripening fruit decreases universally.

Carotenoids

A dramatic synthesis of carotenoids occur during the last step of ripening. It has been reported that the levels of carotenes, free geraniol, mevalonic acid, all precursors of carotene biosynthesis increases progressively during ripening.

Other Pigments

The colour imparted to raw or ripe fruits and vegetables are due to presence of various pigments. The pigments of different tissues are the chlorophyls (green), anthocyanin [reddish to purple], flavonoids [yellow], leucoanthocyanins [colorless], tannins [colorless to yellow or brown], betalains [red], quinones and xanthones [yellowish] and carotenoids [yellow and red].

During storage some of these pigments undergo considerable changes. Carotenoids formation and destruction may be affected by the storage conditions. In certain instances, these reactions are stimulated by O_2, inhibited by light and high temperature. Carotenoids include lycopone, Beta, Gamma carotenes and are synthesized enzymatically in the fruits. Anthocyanin synthesis is stimulated by light and is often affected by temperature. Purple colour of red cabbage intensifies when stored below 10^o C. Chlorophyll degradation is accompanied by synthesis of other pigments as the fruits ripen. Chlorophyll metabolism is markedly influenced by environmental parameters, such as light, temperature and humidity and the effects of these factors are specific for the tissues. For example, light accelerates degradation of chlorophyll in ripening tomatoes and promotes formation of the chlorophyll pigment in cold stored potatoes.

Tannins

The tannins and other polyphenolic constituents are present in abundant quantities in immature, raw or developing fruits. As the maturity and ripening progresses the total polyphenolic content reduces gradually.

Pectic Substances

The most obvious changes during ripening of fruit are the alteration in texture. The plant cell wall is made up of cellulose fibrils embedded in a matrix consisting largely of pectic substances, hemicellulose, proteins, lignins etc and water. Cell wall and middle lamella components increase during development of fruits, but as the fruit ripens the content of soluble pectates and pectinates increase, while total pectic substances decrease.

The cell walls are surrounded by parenchymatous cells, which will absorb water and generate hydrostatic pressure within the living cells. This is called turgor pressure that gives the desirable property of crispness to the commodity. During storage, the loss of moisture due to transpiration and respiration results in the loss of crispness or the turgidity of the commodity. In addition, the changes in the pectic substances – [which form a component of the cell walls of the fruit] – account for the firmness of the fruits. During ripening, the protopectin, which is insoluble and forms, the middle lamella of the cell wall, decreases in quantity and the soluble pectin content rises, thereby making the flesh less firm or soft. A decrease in the chain length and loss of methyl groups of proto-pectin probably occurs during ripening, accounting for the rise in soluble pectin. This is brought about enzymatically mainly by the enzymes pectinase and pectin methyle sterase.

Volatile Products

Each fruit has specific aroma which ripened fruit emanates. Although different fruits vary in nature of volatile compounds, they are emitted in noticeable amount only when the fruit starts ripening. Although the degree of maturity is the main physiological factor affecting aroma production, the aroma composition is also affected by environmental conditions during maturation. In overripe fruits mostly alcohol and esters are formed when fermentation develops.

One of the marked differences between an unripe and ripe fruit is the intensity of flavour of the fruit. The flavour of fruits or vegetables are considered to originate by the presence of basic constituents, such as carbohydrates (particularly mono- and disaccharides], proteins [particularly free amino acids] and fats [triglycerides or their derivatives], as well as vitamins and minerals. These constituents are produced through photosynthetic and related metabolic activities occurring in the commodities. Some volatile compounds may exist in the tissues as such but in some it may be formed enzymatically upon rupture of cells or by microorganisms. Besides ethylene, a number of other volatile odorous constituents like amyl esters of formic, acetic, valeric and caprylic acids have also been identified. These organic emanations produced during ripening of fruits contribute to the aroma of fruits and hence are of considerable importance from the standpoint of fruit quality.

Enzymes

Enzyme action is responsible for many chemical and physical effects during ripening. Softening of fruits, conversion of starch to sugar or vice versa, changes in amino acid content, and enzymes bring changes in color.

Most of the bio-chemical changes occurring in fruits during ripening can be attributed to enzyme reactions. The change from starch to sugar, sucrose to invert sugar or protopectin to pectinic acid are all due to enzymic reactions.

Oxidative enzymes like catalase and peroxidase were shown to have increased to a considerable extent in ‘Alphonso’ and ‘Neelam’ varieties of mangoes during ripening as indicated by the higher rate of respiration. Similarly, glycolytic and hydrolytic enzyme activity were also found to increase in ripening mangoes, particularly during climacteric and post-climacteric stages. Transminase activity also increased in mangoes, resulting in the increased amounts of amino acids. Chlorophyllase activity followed the climacteric pattern in bananas, but suggested that the ensuing chlorophyll degradation may not be relevant to ripening. Other enzyme that increases in activity during ripening and following respiratory climacteric is fatty acid synthatase in Avocado fruit.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What is the effect of planting density on post harvest quality of the horticultural produce?

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2. What is the effect of pre-harvest fertilization on post harvest quality of horticultural produce?

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3. How pre-harvest diseases affect the quality of fresh produce?

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4. What are the effects of low water on fruit quality?

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2.6 LET US SUM UP

The quality of fresh produce depends on many factors during growth and after harvest. The cultural practices followed before harvest has marked effect on fruit quality. A number of physiological and bio-chemical changes take place during growth of the produce that continues after harvest also. Therefore it is important to follow good pre and post harvest practices to extend the shelf life and maintain the quality of horticulture produce.

2.7 KEY WORDS

Morphological changes	:	Visible changes on the outer surface of the product.
Chemical changes	:	Changes in composition of the product.
Ripening	:	The advance stage in the development at which fruit and vegetable are suitable for consumption/ utilization.
Growth	:	Gradual development towards maturity (increase in size, weight, etc.).
Maturation	:	Becoming full grown or fully developed.
Senescence	:	Beginning of final phase in the life of plant.
Cultural practices	:	A set of operations used for raising a crop in the field.
Planting density	:	Number of plants per unit area.
Pruning	:	To cut away or remove unnecessary plant parts.
Thinning	:	Reduction of population of plants.

2.8 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Your answers should include following points:

   - Growth
   - Maturation
   - Senescence

2. Your answers should include following points:

   - Cell wall thickness
   - Plasmalemma
   - Intercellular spaces

3. Your answers should include following points:

   - Chloroplast
   - chromoplast

4. Your answers should include following points:

   - Anabolic
   - Catabolic
   - Aging
   - Death

Check Your Progress Exercise 2

1. Your answers should include following points:

   - Light availability
   - Fruit size

2. Your answers should include following points:

   - Mineral deficiency
   - Mineral toxicity

3. Your answers should include following points:

   - Reduced yield
   - Poor quality

4. Your answers should include following points:

   - Fruit size
   - Splitting
   - Disorders

2.9 SOME USEFUL BOOKS

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