UNIT 8 GROWTH, MATURATION AND SENESCENCE

Structure

8.0 OBJECTIVES

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

- know the chemical changes taking place during growth, ripening and senescence;
- tell about respiratory climacteric;
- explain the factors affecting respiration; and
- mention the morphological changes in fruit tissues during ripening and senescence.

8.1 INTRODUCTION

The life of fruits and vegetables can be divided into three major physiological stages following germination- growth, maturation and senescence. 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. Major changes in carbohydrates, organic acids, pigments and volatiles are observed during growth of the produce, which continue during ripening and senescence.

Food may be stored in various storage organs, such as roots, shoots tubers, rhyzomes, bulbs, corms, fruits and seeds. Storage may take place 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.

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 and 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 served 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.

Fruits and vegetables are highly perishable products with active metabolism during the post-harvest period. Proper handling plays an important role in increasing their 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 biochemical 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 becomes 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 ripening.

Physiology of Ripening

The term "ripening" is generally referred to the physical and biochemical 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 progresses. 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 it 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.

8.2 PHYSICOCHEMICAL CHANGES DURING GROWTH OF STORAGE ORGANS

Carbohydrate

Sugars are important for pleasing fruit flavour (sugar acid ratio) 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.

Many changes occur in carbohydrate fraction of fruit during ripening, the climacteric and senescence. Green or raw fruit usually contains starch in abundance, but is short of 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 Aacids

The organic acids are among the major cellular constituents 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 partly 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 shows a continuous decline. Small increase in protein content was 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 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 occurs 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 chlorophylls (green), anthocyanin [reddish to purple], flavonoids [yellow], leucoanthocyanins [colourless], tannins [colourless 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 lycopene, alpha, beta and gamma carotenes 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 change during ripening of fruit is 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 tugor pressure which 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 forms a component of the cell wall of the fruit cells) account for the firmness of the fruits. During ripening, the proto-pectin, 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 activity of the enzymes pectinase and pectin methyle esterase.

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 enzyatically 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 in colour.

Most of the biochemical 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 was also found to increase in ripening mangoes, particularly during climacteric and post-climacteric period. Aspartie aminotransterase 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.

8.3 MECHANISM OF NUTRIENT MOBILIZATION AND ACCUMULATION

A developing commodity is the complex system of actively metabolizing tissue. Fruit growth generally starts by a short but rapid cell multiplication followed by cell enlargement. Initially cell division and enlargement contribute towards growth, but later cell division becomes major contributory factor. Large quantity of food is accumulated in storage tissue, the composition of which varies with the type of produce. Starch is stored in potato, garlic, banana; fat in avocado; malic acid in apple; citric acid in citrus and pineapple; ascorbic acid in guava; tartaric acid in grapes. Although the nature of chemical stored is a genetic characteristic, the mechanism of storage is physiologically controlled.

Concentration gradient is partly responsible for movement of nutrients from leaves to storage organs. Soluble carbohydrates from leaves are converted to insoluble carbohydrates in storage structure, thus create a gradient for further accumulation. Organic acids are contained inside the vacuoles. Once products are accumulated inside the organ some form of controls occurs to prevent their drain.

Some hormones are involved in the nutrient accumulation in storage organs. Stimulation of nucleic acid and protein synthesis by hormone treatment may cause translocation of nutrients, which establishes a physiological sink.

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 changes in carbohydrates take place during growth and ripening of the product?

………………………………………………………………………………….

………………………………………………………………………………….

………………………………………………………………………………….

………………………………………………………………………………….

2. What is the effect of ripening on chlorophyll and carotenoids?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

3. What kind of food is stored in banana, apple, grape and guava?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

4. How carbohydrates are accumulated in tissues?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

8.4 RESPIRATION AND RESPIRATORY CLIMACTERIC

A major metabolic process occurring in harvested produce or in any living plant product is respiration. Respiration can be described as the oxidative breakdown of the more complex materials normally present in cells, such as starch, sugars and organic acids, into simpler molecules, such as carbon dioxide and water, with the concurrent production of energy and other molecules which can be used by the cell for synthetic reactions. Respiration can occur in the presence of oxygen (aerobic respiration) or in the absence of oxygen (anaerobic respiration, sometimes called fermentation).

Respiration rate of produce is an excellent indicator of metabolic activity of the tissue and thus is a useful guide to the potential storage life of the produce. If the respiration rate of a fruit or vegetable is measured as either oxygen consumed or carbon dioxide evolved – during the course of its development, maturation, ripening and senescence periods, a characteristic respiratory pattern is obtained. Respiration rate per unit weight is highest for the immature fruit or vegetable and then steadily declines with age. A significant group of fruits that includes tomato, mango, banana and apple shows a variation from the described respiratory pattern in that they undergo a pronounced increase in respiration during ripening. Such an increase in respiration is known as a respiratory climacteric and this group of fruit is known as the climacteric class of fruits. The intensity and duration of the respiratory climacteric, varies widely amongst fruit species. The commencement of the respiratory climacteric coincides approximately with the attainment of maximum fruit size and it is during the climacteric that all the other characteristic changes of ripening occur. The respiratory climacteric, as well as the complete ripening process, may proceed while the fruit is either attached to or detached from the plant. Those fruits such as citrus, pineapple and strawberry that do not exhibit a respiratory climacteric are known as the non-climacteric class of fruits. Non-climacteric fruits exhibit most of the ripening changes, although these usually occur more slowly than those of the climacteric fruits. All vegetables can also be considered to have a non-climacteric type of respiratory pattern.

Respiration Rate

Respiration is the process by which stored complex materials are broken into simple products and energy is released. While respiration is essential to maintain the state of living of the produce, it causes deterioration due to losses in food reserves, food value, flavour, and dry weight. The rate of deterioration of harvested produce is generally proportional to their respiration rate. Respiration is linked to many quality parameters, which are responsible for spoilage. The rate of respiration is a good index of post-harvest life of fruits and vegetables as it is directly related to the rate of metabolism. According to respiration rate commodities can be classified as-

Class	Respiration rate (mg CO_2/ Kg/h at 5°C)	Examples
Very low	5	Nuts, dates, dried fruits and vegetables
Low	5-10	Apple, citrus, grape, garlic, onion, potato
Moderate	10-20	Apricot, banana, cherry, peach, plum, pear, cabbage, carrot, tomato, pepper
High	20-40	Strawberry, blackberry, cauliflower, lima beans
Very high	40-60	Snap beans, Brussels sprout
Extremely high	>60	Asparagus, mushroom, pea, spinach

Respiratory Climacteric

Many fruits and vegetables show a rapid increase in respiration during ripening and they are called as climacteric. Fruits that do not show such phenomenon are referred as non-climacteric. Although non-climacteric fruits are also reported to have rise in respiration rate with a concomitant rise in ethylene production or may show this effect at appropriate stage or under appropriate storage condition.

Factors affecting Respiration

A number of factors are responsible for variation in respiration rate. They include internal factors such as stage of development and chemical composition of fruit tissues. External conditions also change respiration rate of the produce.

Stage of Development

During development as fruit size increases the total amount of CO_2 emitted by fruit also increases. In climacteric fruits, the respiration rate is minimum at maturity and remains rather constant, even after harvest. When ripening is about to start, respiration rate rises up to climacteric peak, then it slowly declines. Non-climacteric fruits ripen on tree, and if harvested early, a decline in respiration rate is observed. Actively metabolizing tissue has higher respiration rate. Small sized tissues will have higher respiration rate as they are having larger total surface area.

Chemical Composition of Tissue

The relationship between respiration rate and chemical composition varies among produce. Respiratory quotient varies with the type of substrate being used for respiration. It is 1 when substrate is sugar and less or more than 1 when lipids or organic acids, respectively, are the substrate. The level of moisture can also affect the respiration. Commodities with good natural coatings exhibit low respiration.

External Factors

Temperature: Respiration rate of fruits and vegetables increases 2-2.5 times for every 10°C rise in temperature.

Ethylene: In climacteric fruits exogenous application of ethylene advances the respiratory peak. In the non-climacteric fruits, respiration may be stimulated anytime during the life of the detached fruit, and an immediate rise in respiration occurs after ethylene application.

Oxygen and carbon dioxide: Rate of respiration increases with the increasing supply of oxygen, and carbon dioxide has an opposite effect.

Growth regulators: Depending on the time of application and quantity absorbed by the fruits, growth regulators may inhibit or stimulate the rate of respiration.

Fruit injury: Depending on the fruit variety and severity of bruising, injury can stimulate the respiration. This effect is indirectly attributed to ethylene production.

8.5 CLIMACTERIC AND NON-CLIMACTERIC FRUITS AND VEGETABLES

Climacteric fruits show a large increase in respiration rates and ethylene production as they ripen. In contrast non-climacteric fruits exhibit low CO_2 and C_2H_4 evolution rates during ripening. A non-climacteric fruit reacts to ethylene treatment at any stage of its pre-harvest or post-harvest life, whereas a climacteric fruit exhibit a respiratory response only if ethylene is applied during the pre- climacteric stage, and it becomes insensitive to ethylene treatment after the onset of the climacteric rise Table 8.1.

Table 8.1: Some Examples of climacteric and non-climacteric fruits and vegetables

Climacteric	Non-climacteric
Apricot, banana, mango, avocado, cherry, peach, plum, pear, cabbage, carrot, tomato, pepper Apple, garlic, onion	Strawberry, blackberry, cauliflower, citrus, lima beans, Snap beans, Brussels sprout, grape, cucumber, pomegranate

8.6 MORPHOLOGICAL AND CHEMICAL CHANGES DURING RIPENING AND SENESCENCE

Compositional changes take place in harvested fruits and vegetables, which influence their colour, firmness, taste and aroma. During ripening there is change in colour of many products as the chlorophyll breakdown takes place, and new pigments are synthesized. Changes in carbohydrates include starch to sugar conversion and vice-versa, breakdown of pectins and other polysaccharides, which results in softening of fruit. Changes in organic acids and lipids influence flavour development. Synthesis of volatile organic compounds during ripening emits typical aroma of the commodity.

Many structural changes occur during ripening and senescence. In the sequence of events that leads to senescence of plant cell decrease in ribosome population and chloroplast breakdown are the first detectable symptoms.

Ribosomes

No change in ribosome population during maturation and ripening of tomato was observed as they were distributed throughout the cytoplasm and along the rough endoplasmic reticulum at all stages of fruit development, although a decrease was observed in post climacteric stage.

Mitochondria

A general degradative process is characterized by the reduction in the number of intact mitochondria, as senescence can be termed as the failure of the system responsible for keeping the cells in good repair. In the final stage of senescence, a shortage of ATP resulting from fewer active mitochondria can cause a loss of membrane integrity and redistribution of enzymes and substrate. In general mitochondria appears to be more resistant to breakdown than other organelles, and they persist till late stages of senescence.

Cell Wall

Differences occur in cell wall structure at different stages of fruit development. Loosening of cellulosic fibrillar structure is seen during ripening depending on the degree of solubilization of pectic and hemicellulosic substances between the microfibrils. Thickness of cell wall changes and cells turn round and tend to dissociate.

Plastids

Plastids show more striking changes than all other organelles. As fruit matures, starch granules disappear and the osmophilic granules increase in number and size. With maturity grana disappear and structure similar to thylakoid plexes are seen. In ripe stage, chromoplast development takes place with granal lyses and increase in size and/or number of lipid granules. Generally chlorophyll disappears from senescing plant tissue with degeneration of granal lamellae, formation of a single membrane system, and an increase in size and/or osmiophilic globules.

Intracellular Spaces

Intracellular spaces are formed by separation of cells along the middle lamella. A decrease in porosity is observed with ripening.

Other Cell Organelles

The endoplasmic reticulum vesiculates and disappears with senescence. Golgi apparatus also disappears and tonoplast breakdowns with senescence. The nucleus and plasmalemma are the last structure to vanish and it brings about the death of cell.

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. How developmental stages affect the respiration rate of the product?

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

2. How chemical changes taking place during ripening affect rate of respiration?

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

3. What changes in mitochondria occur during ripening and senescence of the produce?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

4. What are the cell wall changes during ripening and senescence of the produce?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

8.7 LET US SUM UP

Taste of fruits and vegetables is associated with the amount and type of chemical constituents and the physical nature of the commodity at harvest. During ripening a series of changes in colour, texture and flavour are evident. These changes are influence by respiration and ethylene production by the produce. It is important to realize that no improvement in quality can be done in post harvest stage; only efforts can be made to keep intact the quality attained at harvest.

8.8 KEY WORDS

Physiology : Study of the functions and vital processes of living plants.

Ethylene : A colourless flammable gas which stimulates ripening.

Ripening : The advance stage in the development at which fruit and vegetable are suitable for consumption/ utilization.

Climacteric : Fruits/vegetables showing a sudden upsurge in respiration coupled with ethylene evolution.

Non-climacteric	:	Fruits/vegetables who do not show a sudden upsurge in respiration coupled with ethylene evolution.
Respiration	:	Process of inhaling oxygen and exhaling carbon-di-oxide.
Development	:	A process of growth towards more perfect stage.
Maturation	:	Becoming full grown or fully developed.
Senescence	:	Beginning of final phase in the life of plant.
Volatiles	:	A substance having the quality of gas.
Pigments	:	Colouring matter in the cells or tissue of fruits and vegetables.
Aroma	:	A smell coming out of the product.
Fermentation	:	The breaking down of complex organic compound by microorganisms.
Coating	:	Layering of the outer surface of fruits or vegetables.
Bruising	:	To injure the surface without breaking the skin, but causing Discoloration.

8.9 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Your answers should include following points:
   - Pectic substances
   - Starch
2. Your answers should include following points:
   - Chloroplast
   - Chromoplast
   - Mevalonic acid
   - Chlorophyllase
3. Your answers should include following points:
   - Starch
   - Acids
4. Your answers should include following points:
   - Insoluble carbohydrates
   - Gradient

Check Your Progress Exercise 2

1. Your answers should include following points:
   - Fruit size
   - Size and metabolic stage of tissues

2. Your answers should include following points:
   - Sugars
   - Organic acid
   - Lipoids

3. Your answers should include following points:
   - More resistant
   - Membrane integrity

4. Your answers should include following points:
   - Cellulosic fibrillar
   - Pectin solubilization

8.10 SOME USEFUL BOOKS

1. Kader, A.A. (1992) Post-harvest Technology of Horticultural Crops. University of California Publication No 3311, Oakland, Calf.

2. Pantastico, Er. B. (1975) Post-harvest physiology, handling and utilization of tropical and subtropical fruits and vegetables. AVI Pub. Co. Inc., Westport, Connecticut

3. Ryall, A.L. and Lipton, W.J. (1979) Handling, Transportation and Storage of fruits and vegetables. Vol. 2, 2nd Ed. – Vegetables and Melons. AVI Pub. Co.

4. Ryall, A.L. and Lipton, W.J. Handling (1979) Transportation and Storage of fruits and vegetables. Vol. 1, Fruits and Nuts, AVI Pub. Co.

5. Salunkhe D.K., Kadam, S.S. (1995) Handbook of fruit science and technology: Production, composition, storage, and processing. Marcel Dekker, Inc. 270 Madison Avenue, New York, New York.

6. Salunkhe, D.K. and Desai, B.B., Boca Raton, N.W. (1984). Post-harvest biotechnology of vegetables. Vol. I and II, CRC Press, Inc., Florida.

7. Salunkhe, D.K., Kadam, S.S. (1998) Handbook of vegetable science and technology: Production, composition, storage, and processing, Marcel Dekker Inc. 270 Madison Avenue, New York, New York.

8. Weichman, J. and Basel (1987) Post-harvest physiology of vegetable. Marcel Dekker Inc., New York.

9. Wills, R.B.H.; Lee, T.H.; Graham, D.; McGlasson, W.B. and Hall, E.G. (1981) Post-harvest: An introduction to the physiology and handling of fruits and vegetables. AVI Publishing Co. Westport, Conn.