Postharvest Physiology and Handling of Quality Fresh Produce and Ornamentals

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CHAPTER 1
NECESSITY FOR A BASIC KNOWLEDGE OF FRESH PERISHABLE PLANT PRODUCTS

The cultivation and marketing of fresh produce play an important role in the world economy and maintenance of a good quality of life. Cultivation of fruit, vegetables and cut flowers of outstanding quality must always be the aim for the successful marketing of perishable products. Furthermore, each role-player in the various sectors of the fresh produce industry must have a good working knowledge of the many factors that determine the quality of fresh produce. Such knowledge is essential to ensure that good quality products are sent to local and export markets and to reduce postharvest losses to a minimum.

The global fresh produce distribution network involves procedures such as packing, transport, handling, storage, distribution, processing and marketing, and significant losses can occur at any of these points.

Despite the development of sophisticated storage and transport techniques, large amounts of fresh produce perish prior to reaching the consumer. Depending on the type of product and industry involved, each role-player in the fruit and vegetable industry must have a minimum basic knowledge of their product in order to ensure optimum product quality. This includes knowledge of the cytology, physiology, morphology and biochemistry of fresh fruit and vegetables; the complexity of plant cells and tissues; the vegetative origin of different types of fruit and vegetables; the chemical composition and nutritive value of fruit and vegetables; preharvest factors that affect the growth, development and quality of perishable products; fruit ripening, with special reference to climacteric and non-climacteric fruit; quality characteristics and quality evaluation of fruits and vegetables; factors (biological and environmental) involved in the deterioration of harvested fruits and vegetables; changes in the chemical, physiological and biochemical processes associated with ripening and senescence during the postharvest period; effective harvesting procedures; optimum harvesting stage; handling; transport; packing and packing materials; cool storage and storage under controlled and modified atmospheres; other postharvest treatments to extend the shelf life; processing and handling of fresh-cut produce; artificial fruit ripening and simple instruments to be used as aids in the fruit industry.
CHAPTER 2
THE COMPLEX NATURE OF FRESH FRUIT, VEGETABLES AND ORNAMENTALS

Fruits are generally formed from a flower after pollination. It is formed from one or more ovaries and, in some cases, includes structures derived from other floral parts. Although fruits generally contain seeds, there are exceptions where parthenocarpic (seedless) fruit are formed without fertilization (e.g. banana, pineapple and certain grape and orange cultivars).

Vegetables are derived from a wide variety of plant organs and some are actually fruit in botanical terms. Vegetables can be classified into three general groups, viz. bulbs, roots and tubers; flowers, bulbs and leaves; fruit and seeds.

Each type of fruit, vegetable and ornamental consists of a variety of tissues such as epidermis, periderm, parenchyma, collenchyma, sclerenchyma, vessels, xylem (wood vessels, tracheids, xylem vessels, xylem parenchyma), cambium, phloem (sieve elements, companion cells, parenchyma cells), cortex, endodermis and pericycle. These tissues in turn consist of specific cell types characteristic to that tissue. The majority of tissues consist of living, metabolically active cells. A living cell is a complex, highly organized structure, consisting of many different compartments that form one organized system. The complexity of a cell is reflected in the variation, number and nature of subcellular organelles and chemical compounds found therein.

A sound knowledge of the chemical composition of fruit and vegetable tissues is required in order to guarantee the supply of high quality fresh and processed products to local and international markets. Such knowledge is also essential to explain aberrations which may occur in fresh, canned, frozen, stored, packed and processed products. A large variety of chemical compounds are found in plant cells and the chemical composition of different fruit and vegetable types can vary considerably. The chemical composition of a specific cultivar grown at different localities may also vary greatly depending on climate, soil type, cultivation practices, fertilization, irrigation, pruning, weeding, etc. The chemical composition of a specific cultivar grown in a specific location may even vary from year to year as a result of climatic differences between growing seasons. Different chemical compounds found in fruit and vegetables are classified into specific groups according to their chemical characteristics. Some of these groups may be present in some, but absent in other fruit and vegetable types. The number of compounds per group may also vary and great differences in the concentrations of individual compounds can occur.
CHAPTER 3
PREHARVEST FACTORS AFFECTING POSTHARVEST QUALITY

Flowers, fruit and vegetables form an integral part of the plant during the preharvest period. Any factor that negatively affects the plant during this period will, therefore, have a negative impact on these organs that will eventually be reflected in the quality of the harvested product. Normal plant growth is affected by both aerial and soil factors. Aerial factors include microorganisms (fungi, bacteria, and viruses), pesticides, herbicides, temperature, light, humidity, carbon dioxide, air pollutants, pruning, bark damage, grafts, wind, hail and abrasions. Soil factors include soil type, soil preparation, soil water, soil pH, soil temperature, fertilization, salinity, herbicides, microorganisms and nematodes.

Commercial growers of cut flowers, fresh fruit and vegetables must have a sound knowledge of all the factors that may affect the quality of their produce. Commercial traders of fresh produce must be familiar with the source of their produce and how such produce are affected by these factors.
CHAPTER 4

RESPIRATION PATTERNS OF PERISHABLE COMMODITIES

The development of a fruit or other plant organ can, for the sake of convenience, be divided into three phases, viz. growth, maturation and ripening/senescence. However, it is not possible to clearly identify the transition from one phase to the next, since considerable overlap exists between the major processes characteristic of each phase and the next phase may commence before the previous one is completed. The first two phases can only be completed while the organ is still attached to the plant. Fruit can ripen on or off the plant, depending on the type of fruit and the stage of development at which it is harvested. Fruit are usually harvested after the growth phase at full maturity. When an organ such as a fruit, leaf or flower is removed from the plant, it remains alive and the normal biochemical and physiological processes continue to occur. However, water and respiratory substrates are no longer supplied by other plant parts, resulting in wilting due to continued transpiration and depletion of reserves that leads to accelerated senescence. The rate of respiration during the postharvest period is characteristic for each commodity and is dependent on the environmental conditions at which the commodity is kept.

Different commodities differ from each other with relation to their patterns of respiration during the postharvest period. The large variety of fruit, vegetable and flower types found all over the world are classified into two groups on the basis of their respiratory behaviour, viz. climacteric and non-climacteric. The respiratory pattern of climacteric commodities is characterized by a sudden peak in respiration during the final phases of development. These commodities can be harvested at full maturity and allowed to ripen off the plant. In non-climacteric commodities no rise in respiration occurs during ripening and senescence. The respiration rate remains constant or declines gradually during the postharvest period. Non-climacteric fruit are usually harvested when fully ripe. Ripening does not occur off the plant and is not accelerated by ethylene.
CHAPTER 5
PLANT HORMONES AND THE CONTROL OF SENESCENCE AND RIPENING

All known metabolism is programmatically organized and controlled through the genetic information of the cell. Senescence and ripening are consequently genetically controlled, but can be affected by environmental conditions. The programmed control of the processes involved in ripening and senescence is accurately regulated through the interaction between different plant hormones. Some of these hormones, such as cytokinins and gibberellins, are known to delay senescence and ripening, while others, such as ethylene, are commonly known to accelerate senescence and ripening in climacteric tissues. Ethylene is a unique plant hormone involved in various aspects of plant growth and development. In climacteric tissues, ethylene synthesis follows a pattern very similar to respiration. Ethylene production remains very low during the pre-climacteric phase and increases rapidly concurrently with the climacteric rise in respiration rate. However, in non-climacteric tissues, the rate of ethylene synthesis remains constantly low throughout ripening and senescence. Ethylene plays an important role in the ripening and senescence of climacteric tissues. It stimulates respiration and, thus, heat production. In fruit, it stimulates softening and the hydrolysis of cell walls by stimulating the transcription of enzymes such as polygalacturonase and cellulase. Ethylene also stimulates the breakdown of chlorophyll and the increase in membrane permeability associated with ripening and senescence. In addition, ethylene also causes changes in the metabolism of carbohydrates, organic acids and proteins, and stimulates the production of aroma compounds during fruit ripening. In climacteric flowers, ethylene causes wilting, colour changes and inrolling of petals as seen in carnations. Ripening and senescence can be inhibited by treatment with inhibitors of ethylene synthesis and action such as AVG, AOA, silver thiosulfate (STS), and 1-methylcyclopropene (1-MCP). The first two compounds are inhibitors of ethylene synthesis, while the latter is a gaseous compound that inhibits ethylene action by binding competitively to the membrane associate ethylene receptors. However, ripening and senescence can never be stopped completely by the inhibition of ethylene synthesis or action.
CHAPTER 6
QUALITY DETERMINATION AND MANAGEMENT

With respect to fruits and vegetables, quality refers to the degree of excellence of attributes such as appearance, eating quality, handling and transport quality, shelf and storage quality, nutrition, internal quality and maturity. Quality has different meanings to different role-players in the handling network. Producers, transporters and marketers of fresh, fresh-cut, dried, frozen and processed produce all have different preferences with regard to quality when handling and buying a product. Although quality for these role-players may be defined as "fitness for purpose", quality is finally determined by acceptability to the final consumer. This means that judgment of final quality is often highly subjective and based on consumer preferences and experience. Due to the subjective nature of quality determination, no quality standard exists for any product that will satisfy all consumers. Therefore, a balanced view of quality that is both product and consumer oriented is required. From the consumer’s perspective, quality criteria include aspects such as external appearance, texture, flavour (taste and aroma), nutritive value and shelf life. External appearance plays a primary role in the evaluation of a product and is the most important quality factor used by the consumer to determine the acceptability of a fresh product. Appearance is determined by the visual evaluation of size, shape, colour, degree of shrivelling or wilting, absence of defects, deviations from typical cultivar traits, residues of foreign substances, damage by chemicals or gasses, damage by microorganisms or insects and symptoms of physiological disorders. It is advisable to have some knowledge of each of these different aspects. Since the quality of fresh produce is determined by a combination of various characteristics, attributes and properties, quality is measured commercially by testing a variety of physical and chemical characteristics. These include soluble solids content (refractometer, near infrared spectroscopy), pH (pH-meter), titratable acidity (titration of juice with NaOH), peel and flesh colour (subjectively through the use of colour charts or objectively with a hand-held colorimeter or standardized electronic sorting), size and shape (size and shape charts, weight, circumference, diameter), absence of defects (scoring system, near infrared imaging), firmness (penetrometer, densitometer, acoustic analyzer, impact tester), conversion of starch to sugar (iodine test), flavour (taste, smell, gas chromatograph, electronic nose), gloss (gloss meter), nutrients and chemical residues (chemical analysis). A variety of instruments have been developed or adapted for this purpose.
CHAPTER 7
RIPENING AND SENESCENCE OF FRESH PRODUCE

Fresh produce harvested at maturity have a limited shelf life that is reduced even further if the produce are not stored at the optimum low temperature immediately after harvest. The limited postharvest life can be attributed to the reliance of metabolic processes that continue as usual after harvest, on the availability of limited reserves of metabolites, nutrients and water accumulated in the product prior to harvest. Factors that can speed up the postharvest deterioration of the product, as well as the time from harvest to consumption must therefore be limited to a minimum. All possible measures must be taken to preserve the original freshness of the product during the postharvest period.

As soon as fruit, flowers or other organs are removed from the plant, their natural supply of nutrients, water and metabolites form the rest of the plant is cut off and numerous undesirable processes set in. Cellular degradation progresses slowly and becomes irreversible when catabolism (the breakdown of complex molecules to from simpler ones, together with the release of energy) exceeds anabolism (the synthesis of complex molecules from simpler ones, together with the storage of energy). At this point storage at low temperatures will have a very limited effect in delaying cellular breakdown. The higher the rate of respiration, the faster is the rate of breakdown and the shorter is the longevity of the commodity. A fresh product may consist of different tissues that deteriorate at different rates. Cells of the same tissue may even deteriorate at different rates, e.g. avocados ripen from the stalk end and bananas soften from the middle towards the ends of the fruit during ripening.

Plant tissues undergo numerous complex cytological, biochemical and physiological changes during ripening and senescence. The rate of such changes varies considerably between different commodities and even between cultivars. Typical changes that occur during ripening and senescence include texture changes (softening) due to the breakdown of cell walls, colour changes due to breakdown and/or synthesis of pigments, production of volatile aroma compounds, conversion of starch to soluble sugars, changes in respiration rate, an increase in ethylene production, changes in the composition and levels of various metabolites, build up of waxy deposits on the peel surface, maturation of seeds, an increase in membrane permeability and ultrastructural changes.
CHAPTER 8
HARVESTING, SORTING, PACKING AND PACKAGES

It is of utmost importance to harvest perishable commodities, especially fruit and flowers, at the correct stage of development. A basic knowledge of the correct stage of development at which different commodities should be harvested, as well as the availability of appropriate maturity indices, guidelines and directions, is essential to preserve quality and obtain maximum storage and shelf life. The maturity at harvest affects storage and shelf life, appearance, flavour, texture, development of physiological disorders, fungal infection and, therefore, market value. Harvesting at the incorrect stage of maturity can result in rejection of a commodity for export purposes and thus cause huge losses in revenue. For fruit, optimum maturity is best defined as that stage in the development of the fruit that will ensure the postharvest completion of ripening to an acceptable eat ripeness. A variety of maturity indices have been developed to determine the correct stage of development at which different fruits can be harvested. These indices are based on factors such as peel and flesh colour (colour charts, colorimeter), seed colour, flesh firmness (penetrometer, densitometer), tenderness, soluble solids content (SSC, refractometer), titratable acidity (TA, titration of juice with 0.1 N NaOH), SSC/TA ratio, starch content (iodine test), fruit shape, days after full bloom (DAFB), fruit removal force (FRF, force required to remove fruit from the plant), development of an abscission layer, etc. Fruit and vegetables intended for fresh consumption, as well as cut flowers, are mostly harvested by hand. Produce intended for fresh consumption are harvested into baskets, small plastic lugs, bags, plastic buckets or reusable crates. Cut flowers are usually placed in buckets containing clean water or a suitable preservative solution immediately after harvest. The harvested product is then transferred to field lugs or bins and transported to the packing shed where they are cleaned, sorted, trimmed, treated and packed into packages of various sizes and shapes before shipping to national and international markets. After sorting and grading, perishable commodities are packed into packages of various sizes and shapes for shipping to local and international markets. Packing is done to facilitate distribution and protect the commodity against damage. Damage can result from vibration, impacts and compression of the product. To prevent such damage, the product must be properly immobilized and cushioned by wrapping, using preformed trays and cups, and suitable padding material. Although the package requirements vary widely depending on the type of product, storage and transport methods, marketing requirements, etc., the general purpose of horticultural packages is to assemble the product into conveniently sized units for transfer from the site of production to the point of sale or consumption, and to immobilize and protect the product from injury during storage and transport.
CHAPTER 9
STORAGE OF FRESH PRODUCE

All harvested fresh produce consist of living tissues that respire actively. Part of the energy released during respiration is used to drive tissue metabolism. Approximately 56% of the total free energy available from the complete oxidation of glucose is preserved within the system, while the rest is released as heat. The higher the rate of respiration, the more heat is released. This generation of respiration heat gives rise to an increase in the temperature of the commodity, which in turn stimulates the rate of respiration and, therefore, the rate of heat emission. The generation of respiration heat must be taken into consideration during the transport and storage of fresh produce, since an increase in temperature will stimulate respiration and heat emission and the consequential loss of stored reserves means decreased food value, loss of flavour, loss of saleable weight, accelerated senescence and decreased longevity. Next to humidity, temperature is the most important factor in maintaining quality after harvesting and plays a key role in determining product longevity. For this reason, storage and transport temperatures must be kept as low as possible without causing injury to the tissue. Low temperatures cause a decrease in moisture loss by living plant tissues, a decrease in bacterial and fungal infections and suppress various metabolic processes associated with ripening and senescence. This means that a decrease in temperature will ensure quality retention and an extended storage and shelf life for the commodity. In climacteric commodities, a decrease in temperature will delay the onset of ripening and senescence, while in non-climacteric commodities it will suppress the rate of senescence and deterioration. There is an exponential relationship between the decrease in temperature and the rate of ripening or senescence. The postharvest life of commodities is approximately halved for each 10°C increase in temperature. As a result of the suppression of respiration and general metabolism, the storage period of most commodities can be increased by low temperatures. In general, the rule holds true that the lower the temperature, the longer the storage life of the commodity. In chilling sensitive commodities (e.g. tropical and subtropical commodities) storage at very low temperatures results in chilling injury. Such commodities must be stored at the lowest possible temperature that will not cause injury. Storage in a modified or controlled atmosphere where the concentration of O₂ has been reduced and that of CO₂ increased can significantly extend product longevity provided that the changed O₂ and CO₂ levels fall within the range tolerated by the commodity.
CHAPTER 10
TRANSPORT OF FRESH PRODUCE

Transport and distribution of unprocessed and partially processed fresh produce and ornamentals are key aspects of an extended handling network in which there can be several handover points before it eventually reaches the consumer. Fresh produce are transported from the producer to centralized fresh produce markets where it is purchased by wholesalers and retailers and distributed to a wide variety of marketing outlets. In addition, large quantities of fresh produce are purchased by large chain stores directly from producers and transported to their distribution centers, and from there to their retail outlets. Large retailers often source fresh horticultural produce from producers in foreign countries from where it is then transported by air or sea to distant outlets. Fresh produce are also exported by individual producers or producer cooperatives to foreign markets all over the world, either by air or sea depending on the nature of the product. Moreover, horticultural produce are often sold by small-scale producers directly to consumers and small retailers and transported to remote destinations. In this extensive distribution network, fresh produce can spend a significant part of their postharvest life in transit, especially if they are shipped by marine transport. As a result of long transport times, extensive losses can occur in transit if the produce is not handled properly and the management of the transportation process is poor. The cold chain must be kept unbroken at all times to ensure the maintenance of product temperature. Refrigeration systems are used to maintain low temperatures in trucks and shipping containers. Cold air must be able to flow unobstructed over, through and under the load in order to effectively remove respiration heat. For this reason, loads should not be stacked so tightly into the truck or container that it obstructs air flow. The temperature in the cargo hold can be controlled by placing thermocouples in the in- and outlet ducts of the refrigeration system. Temperature data loggers should be installed at strategic locations in trucks and containers to monitor the temperature during the trip. The temperature of the product can also be monitored by placing thermocouples in the packaging and connecting it to recorders when the product is loaded. Mixed loads must be set up so that the different commodities are compatible in terms of temperature, ethylene and odour.
Most fruit will reach optimum eat ripeness if left to ripen on the plant. However, many climacteric fruits are harvested at optimum maturity when still unripe so that they can better withstand postharvest handling, storage and transport to distant markets. A variety of indices have been developed to gauge the maturity of such fruit and determine when they are ready to be harvested (see Chapter 8). Harvested mature unripe climacteric fruit can be ripened under specific controlled conditions to an acceptable eat ripeness immediately after harvest, or after long term cold storage. Non-climacteric fruit, on the other hand, must be allowed to reach an acceptable eat ripeness prior to harvest since they will not complete the ripening process off the plant. Some non-climacteric fruit such as oranges are sometimes treated with ethylene under controlled conditions after harvest to facilitate complete degreening. However, such treatments do not affect the original ripeness and eat quality of these fruits at harvest. Climacteric fruit can be treated with ethylene to accelerate the ripening processes and facilitate uniform ripening of all the fruit in a package. However, it is essential that such fruit are harvested at optimum maturity in order to reach optimum eat quality after ripening is completed. Fruit ripening is done in specialized airtight rooms equipped with systems and equipment to control ethylene, CO$_2$, temperature and RH. Fruit ripening can also be done in transit during long-distance transport to distant markets. Airtight refrigerated highway trucks/trailers and marine containers can be equipped to facilitate fruit ripening in transit.

Fresh produce are irradiated with ionizing rays such as x-rays, gamma (γ) rays and electron rays so as to destroy microorganisms (especially fungi on fruit) and insects, suppress sprouting (e.g. potatoes), inhibit growth (e.g. asparagus and mushrooms) and delay ripening (e.g. bananas, mangoes and papayas). For these purposes, irradiation is done at dosages ranging from 0.05 to 1.0 kilogray (kGy). Extending the longevity of fresh produce through irradiation with γ-rays requires an optimum dose for each product that will suppress its respiration and will not induce stress.

Heat treatment of fresh produce (temperature preconditioning) is practiced for disinfestation and the control of postharvest fungal decay (disinfection). The purpose of heat treatments is, in part, to replace hazardous chemicals that are used for insect and fungal control. It is important to note, however, that heat treatments that are optimal for insect control may not be suitable for fungal control. Fresh produce are heat-treated by means of hot forced-air (HAT), hot water (HWT) or vapour heat (VHT) before storage and shipment.
CHAPTER 12
FRESH-CUT FRUIT AND VEGETABLES

Fresh-cut produce refers to fresh fruit and vegetables that are cleaned, peeled, trimmed, cut and packed to present fresh produce to the consumer in a convenient, partially or minimally processed form. Such produce remain in the fresh state and are not frozen or heat processed. Minimal processing adds value to the product because it makes a wholesome, flavourful product available in a convenient ready-to-use or cook form, thus greatly reducing the time and effort required by the consumer to prepare the product for consumption. In addition, wastage by the consumer is reduced to a minimum since fresh-cut produce are 100% usable. Another advantage of fresh-cut produce is that it requires less storage space than its unprocessed counterparts due to the removal of unusable parts. Since only the usable portion of a product is packed, considerable savings are also made on transport costs. Although large quantities of fresh-cut produce are prepared especially for the food service industry, fast food outlets and restaurants, its increasing popularity with individual consumers resulted in an exceptional growth in the fresh-cut industry worldwide. Examples of produce marketed in this manner are: cut or sliced green beans and carrots; salad mixes; various kinds of lettuce; peeled and cut pumpkin and squash; cut cauliflower, broccoli and cabbage; peeled and cut potatoes and sweet potatoes; cleaned and cut onions; cleaned and trimmed sweet and baby corn; peeled and cut fruit such as apple, banana, kiwi fruit, melon, nectarine, papaya, peach, pineapple, watermelon, etc. Fresh-cut vegetables such as cabbage, cauliflower, broccoli and carrots usually have a longer shelf life than other fresh-cut vegetables. Fruit are generally more perishable than vegetables and the shelf life of fresh-cut fruit is limited to a few days. Due to their highly perishable nature, fresh-cut produce have strict temperature and sanitary requirements and exhibit greater variation in quality and shelf life than intact produce.
CHAPTER 13
CUT FLOWERS

The cultivation of and trade in cut flowers is a rapid growing worldwide industry. Since cut flowers are often shipped over long distances from the grower to local and international markets, the limited postharvest life of fresh cut flowers is one of the main concerns pertaining to the cut flower industry. Transport over long distances often results in considerable loss in quality and thus longevity. It is in the interest of growers, distributors, exporters, florists and consumers that cut flowers remain fresh as long as possible after harvest. Consequently, the implementation of efficient handling practices and application of effective preservatives contribute considerably to extend the postharvest life and improve and expand the cut flower industry to the advantage of the final consumer.

Structural, physiological and chemical changes associated with cut flower senescence include changes in membrane permeability and viscosity, ultrastructure, gene expression and protein synthesis, respiration, hormone composition and action, pigmentation and a rapid breakdown of starch and cell wall constituents. Such changes are enhanced as soon as the flower is removed from the mother plant and deprived of its regular supply of water, hormones and nutrients from the rest of the plant. It is essential to delay the changes associated with senescence as long as possible in order to extend the vase life of cut flowers. This can be done by the application of proper postharvest practices in conjunction with suitable floral preservatives.