Postharvest Management of Fruits and Vegetables Storage

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***Be** the change you want to see in the world.*

Mahatma Gandhi

Abstract Sustainable agriculture is a core part of the concept of sustainable development. Given the forecast in population increase, sustainable agriculture has to achieve food security in combination with economic viability, social responsibility and have as little effect on biodiversity and natural ecosystems as possible. Based on Agenda 21, signed at the world summit in Rio de Janeiro 1992, sustainable agriculture takes a truly global perspective. This concept requires a thorough understanding of agro-ecosystem functions. The protection of soil and water is one necessary pre-requisite as well as the efficient use of mineral and organic fertilizers. This might be achieved by means of improved technology and better understanding of the basic processes in soils. Solving the persistent hunger problem is not simply a matter of developing new agricultural technologies and practices. Most poor producers cannot afford expensive technologies. They will have to find new types of solutions based on locally-available and cheap technologies combined with making the best of natural and human resources. Sustainable intensification is the use of the best available technologies and inputs such as best genotypes, best agronomic management practices and best postharvest technologies to maximize yields, while

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at the same time minimizing or eliminating harm to the environment. Clearly, over the next 50 years we will need to learn to do just this. Therefore, this review will be focused on the postharvest physiology and management including harvesting, handling, packing, storage and hygiene of fruits and vegetables to enhance using of new postharvest biotechnology. The postharvest biology including biochemical parameters of horticultural crops quality, postharvest handling under extreme weather conditions, potential impacts of climate changes on vegetable postharvest and postharvest biotechnology will be also highlighted.

Keywords Postharvest • Preharvest • Postharvest management • Postharvest losses • Storage science • Biotechnology

1 Introduction

Postharvest physiology is the scientific study of the physiology of living plant tissues after they have denied further nutrition by picking. It has direct applications to postharvest handling in establishing the storage and transport conditions that best prolong shelf life. An example of the importance of the field to post-harvest handling is the discovery that ripening of fruit can be delayed, and thus their storage prolonged, by preventing fruit tissue respiration. This insight allowed scientists to bring to bear their knowledge of the fundamental principles and mechanisms of respiration, leading to post-harvest storage techniques such as cold storage, gaseous storage, and waxy skin coatings. Another well known example is the finding that ripening may be brought on by treatment with ethylene.

The fruit processing industry is one of the major businesses in the world. While basic principles of fruit processing have shown only minor changes over the last few years, major improvements are now continuously occurring, and more efficient equipment capable of converting huge quantities of fruits into pulp, juice, dehydrated, frozen, refrigerated products, etc. make possible the preservation of products for year-round consumption. The fruit processing and storage, even under the most industrially available “mild conditions,” involves physical and chemical changes that negatively modify the quality. These negative or deteriorative changes include enzymatic and non-enzymatic browning, off-flavor, discoloration, shrinking, case hardening, and some other chemical, thermo-physical, and rheological alterations that modify the nutritive value and original taste, color, and appearance of fruits. The ability of the industry to provide a nutritious and healthy fruit product to the consumer is highly dependent on the knowledge of the quality modifications that occur during the processing.

In postharvest, fresh harvested food crops can be considered isolated small scale systems. Postharvest research aims to understand the quality of these ‘systems’ as influenced by postharvest conditions. The phenotypic quality of horticultural produce is based on genetic traits that are expressed through a cascade of reactions subject to complex regulatory mechanisms and diverse environmental conditions. Ultimately, to fully understand postharvest phenomena, a systemic approach that links genetic and environmental responses and identifies the underlying biological networks is required. Thanks to the development of high throughput omics techniques such system-wide approaches have become a viable option to support traditional postharvest research (Hertog et al. 2011).

The structure of a biological system is defined by its physical parts e.g., tissues, cells, organelles and their composition e.g., DNA, proteins, metabolites, lipids. Their behaviour involves inputs e.g., external stimuli such as light, temperature, atmospheric composition, pH and nutrient levels and internal stimuli such as proteins, metabolites, hormones and various other compounds that might act as signal molecules, processing e.g., via catabolic and anabolic pathways, or processes such as gene expression, differentiation and cell division and outputs of material e.g., proteins, metabolites, information e.g., transcripts or energy e.g., heat, ATP, movement. Finally, a biological system is characterized by a high degree of interconnectivity between its various parts, showing both functional relationships e.g., through metabolic, signaling and gene regulation pathways and structural relationships between each other e.g., through compart-mentalization, receptor molecules, membrane transporters, plasmodesmata, vascular tissue, and the cytoskeleton. Systems biology relies on a multidisciplinary approach to integrate data from various disciplines of biology (Friboulet and Thomas 2005) bringing together molecular disciplines e.g., genetics, biochemistry, molecular biology with those involving more complex systems e.g., cell biology, microbiology, plant or human physiology. The aim of systems biology is to link the quantitative data in a mathematically defined sense across the different scales of biological organization from DNA, RNA, protein to cell, tissue, organs. Mathematical modelling is used to drive integration with an aim of reaching a unified understanding of biological systems (Hertog et al. 2011).

In this review, we have tried to address the following questions. First, what examples do we have of specific postharvest physiological or biochemical traits that have been used to improve crops and more specifically, to improve the environmental sustainability of the agricultural production system? Second, what have been the real effects of these advances on agricultural sustainability? Third, how can researcher's best make postharvest of crops research relevant to the challenge of environmental sustainability? Finally, how can producers use these postharvest technological advances in a viable and sustainable manner to improve their productivity and profitability? These issues will be inspired us to look back at the history of agricultural technologies to determine which ones are more sustainable with a view to providing a discussion of the future focus of researchers, government agencies and the agricultural community.

2 Postharvest Management

Postharvest management is a set of post-production practices that includes: cleaning, washing, selection, grading, disinfection, drying, packing and storage. These eliminate undesirable elements and improve product appearance, as well as ensuring that the product complies with established quality standards for fresh and processed products. Postharvest practices include the management and control of variables such as temperature and relative humidity, the selection and use of packaging, and the application of such supplementary treatments as fungicides (FAO 2009).

After they are harvested, the value of fruits and vegetables is added in successive stages up to the point when someone eats them. The aim of postharvest management is to maximize this added value. This ultimately should benefit the whole community, whether through increased export earnings or extending the availability of fresh produce through the year. Conversely losses hurt everyone. Kader (1992) has estimated that from 5 to 25 % of fruit and vegetables leaving the farm gate is never consumed, but has to be thrown away. Obviously, disease and oversupply contribute to this, but there are many other reasons for the losses. Postharvest management can influence all them, with the two most important areas being temperature management and packaging. Another point to remember is that the loss of value of a down graded product is likely to be substantially greater for highly differentiated branded products which sell at a premium in the market. All the hard work that has gone into promoting and raising the profile of a branded product can be quickly eroded if there are postharvest quality problems with some lines of that product (Jobling 2002).

It could be addressed the postharvest management through the following items:

2.1 The Nature of Postharvest Management

The horticultural produce includes fruits, vegetables, flowers and other ornamental plants, plantation crops, aromatic and medicinal plants and spices. According to Oxford English Dictionary, fruit can be defined as '*the edible product of a plant or tree, consisting of seed and its envelope, especially the latter when it is juicy or pulpy*'. The consumer definition of fruit would be 'plant products with aromatic flavors, which are either naturally sweet or normally sweetened before eating. The classification of fruits and vegetables is arbitrary and according to usage. Botanically many crops, defined as vegetables, are fruits e.g., tomato, capsicum, melons etc. Morphologically and physiologically the fruits and vegetables are highly variable, may come from a root, stem, leaf, immature or fully mature and ripe fruits. They have variable shelf life and require different suitable conditions during marketing. All fresh horticultural crops are high in water content and are subjected to desiccation (wilting, shriveling) and to mechanical injury. Various authorities have estimated that 20–30 % of fresh horticultural produce is lost after harvest and these losses can assume considerable economic and social importance. That is why, these perishable commodities need very careful handling at every stage so that deterioration of produce is restricted as much as possible during the period between harvest and consumption (Dhatt and Mahajan 2007).

Horticultural produce is alive and has to stay alive long after harvest. Like other living material it uses up oxygen and gives out carbon dioxide. It also means that it has to receive intensive care. For a plant, harvesting is a kind of amputation. In the field it is connected to roots that give it water and leaves which provide it with the food energy it needs to live. Once harvested and separated from its sources of water and nourishment it must inevitably die. The role of postharvest handling is to delay that death for as long as possible. Horticultural managers must posses many skills to succeed in this. They need a keen appreciation of horticultural diversity. For example, spinach and apples, bananas and potatoes each have their own requirements. The optimum postharvest management of horticultural products is not the same for all products. Growers, wholesalers, exporters and retailers must all be aware of the specific needs of a product if the postharvest shelf life and quality is to be maximized (Jobling 2002).

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2.2 Understanding Product Maturity

The stage of development at which a product is regarded as mature depends on its final use. Fruit and vegetables are eaten at all stages of development. We eat sprouted seeds, vegetative leaves and flowers, whole fruit as well as seeds and nuts. There are no general rules when it comes to defining horticultural maturity. A lot of research has been done to establish maturity parameters for a whole range of specific horticultural products. Maturity must be defined for each product in some cases for each variety of a particular product. The use of maturity standards provides consumers with a minimum level of quality assurance. Another reason for establishing maturity standards is that most horticultural products are harvested by hand. A simple color guide and size can help pickers harvest produce at the correct stage of development (Fig. 1 and Table 1; Jobling 2002).

Maturity at harvest is the most important factor that determines postharvest-life and final quality such as appearance, texture, flavor, nutritive value of fruit-vegetables. Fruit-vegetables include two groups: (1) immature fruit-vegetables, such as green bell pepper, green chili pepper, cucumber, summer (soft-rind) squash, chayote, lima beans, snap beans, sweet pea, edible-pod pea, okra, eggplant, and sweet corn; and (2) mature fruit-vegetables, such as tomato, red peppers, muskmelons (cantaloupe, casaba, crenshaw, honeydew, persian), watermelon, pumpkin, and winter (hard-rind) squash. For group (1), the optimum eating quality is reached before full maturity and delayed harvesting results in lower quality at harvest and faster deterioration rate after harvest. For group (2) most of the fruits reach peak eating quality when fully ripened on the plant and, with the exception of tomato, all are incapable of continuing their ripening processes once removed from the plant. Fruits picked at less than mature stages are subject to greater shriveling and mechanical damage,

Fig. 1 The stage of development at which a product is regarded as mature depends on its final use. Fruit and vegetables are eaten at all stages of development (Photos of some different fruits at maturity stage were taken in Cesena, Italy by M. Fári)

Table 1 Approximate number of days from planting to market maturity under optimum growing conditions

Crop	Early variety	Common type	Late variety
Beans, bush	46	–	65
Beans, pole	56	–	72
Beans, lima, bush	65	–	78
Beets	50	–	80
Broccoli, sprouting[a]	70	–	150
Brussels sprouts[b]	90	–	100
Cabbage[b]	62	–	110
Carrots	60	–	85
Cauliflower, snowball type[b]	55	–	65
Chinese cabbage	70	–	80
Chives	–	90	–
Corn	70	–	100
Cucumber	60	–	70
Eggplant	70	–	85
Kohlrabi	55	–	65
Lettuce, head	60	–	85
Lettuce, leaf	40	–	50
Melon, Honey Ball	–	105	–
Melon, Honey Dew	–	115	–
Muskmelon	75	83	90
Mustard	40	–	60
Okra	50	–	60
Onions	85	–	120
Parsley	70	–	85
Parsnips	100	—	130
Peas	58	–	77
Pepper, sweet[b]	60	–	80
Potatoes	90	–	120
Pumpkin	110	–	120
Radishes	22	–	40
Radishes, winter type	50	–	60
Rutabagas	–	90	–
Spinach	40	–	50
Squash, winter	50	–	68
Squash, summer	80	–	120
Tomatoes[b]	65	–	100
Turnips	40	–	75
Watermelon	65	75	95

Adapted from Smith (2010)
When these crops are planted under low-temperature conditions, reaching the harvest stage will take longer than indicated above
[a]For a direct-seeded crop. Transplanting may delay maturity by a few weeks, depending on environmental conditions
[b]For a transplanted crop, additional time is needed from seed sowing to transplanting

and are of inferior flavor quality. Overripe fruits are likely to become soft and/or mealy in texture soon after harvest. The necessity of shipping mature fruit-vegetables long distances has often encouraged harvesting them at less than ideal maturity, resulting in suboptimal taste quality to the consumer (Kader 1995).

Several factors in addition to maturity at harvest have major impacts on postharvest behaviour and quality of fruit-vegetables. Fruits of group (1) normally produce only very small quantities of ethylene. However, they are very responsive to ethylene and can be damaged by exposure to 1 ppm or higher concentrations. Ethylene exposure accelerates chlorophyll degradation, induces yellowing of green tissues, encourages calyx abscission (eggplant), and accelerates fruit softening. Most of the fruits in group (2) produce larger quantities of ethylene in association with their ripening, and exposure to ethylene treatment will result in faster and more uniform ripening as indicated by loss of chlorophyll (green color), increase of carotenoids (red, yellow, and orange colors), flesh softening and increased intensity of characteristic aroma volatiles (Fig. 2).

All fruit-vegetables, except peas and sweet corn, are susceptible to chilling injury if exposed to temperatures below 5 °C e.g., cantaloupe, lima bean, snap bean, 7.5 °C e.g., pepper, 10 °C such as cucumber, soft-rind squash, eggplant, okra, chayote, or 12.5 °C e.g., tomato, muskmelons other than cantaloupe, pumpkin, hard-rind squash. A relative humidity range of 90–95 % is optimum for all fruit-vegetables except pumpkin and hard-rind squash where it should be 60–70 %. Atmospheric modification (low oxygen and/or elevated carbon dioxide concentrations) can be

Fig. 2 Photo of some different vegetables at maturity stage in super market was taken in China by M. Fári

a useful supplement to proper temperature and relative humidity in maintaining postharvest quality of some fruit-vegetables, such as tomato and muskmelons (Kader 1995).

Fruits harvested too early may lack flavor and may not ripen properly, while produce harvested too late may be fibrous or have very limited market life. Similarly, vegetables are harvested over a wide range of physiological stages, depending upon which part of the plant is used as food. For example, small or immature vegetables possess better texture and quality than mature or over-mature vegetables. Therefore, harvesting of fruits and vegetables at proper stage of maturity is of paramount importance for attaining desirable quality. The level of maturity actually helps in selection of storage methods, estimation of shelf life, selection of processing operations for value addition etc. The maturity has been divided into two categories i.e. physiological maturity and horticultural maturity:

- **Physiological maturity**: It is the stage when a fruit is capable of further development or ripening when it is harvested i.e. ready for eating or processing.
- ***Horticultural maturity***: It refers to the stage of development when plant and plant part possesses the pre-requisites for use by consumers for a particular purpose i.e. ready for harvest (Dhatt and Mahajan 2007).

Importance of maturity indices:

- Ensure sensory quality (flavor, color, aroma, texture) and nutritional quality.
- Ensure an adequate postharvest shelf life.
- Facilitate scheduling of harvest and packing operations.
- Facilitate marketing over the phone or through internet (Table 2).

Definitions related to maturity and ripening:

(i) **Mature**: It is derived from Latin word '*Maturus*' which means ripen. It is that stage of fruit development, which ensures attainment of maximum edible quality at the completion of ripening process.

(ii) **Maturation**: It is the developmental process by which the fruit attains maturity. It is the transient phase of development from near completion of physical growth to attainment of physiological maturity. There are different stages of maturation e.g. immature, mature, optimally mature, over mature.

(iii) **Ripe**: It is derived from Saxon word '*Ripi*', which means gather or reap. This is the condition of maximum edible quality attained by the fruit following harvest. Only fruit which becomes mature before harvest can become ripe.

(iv) **Ripening**: Ripening involves a series of changes occurring during early stages of senescence of fruits in which structure and composition of unripe fruit is so altered that it becomes acceptable to eat. Ripening is a complex physiological process resulting in softening, coloring, sweetening and increase in aroma compounds so that ripening fruits are ready to eat or process. The associated physiological or biochemical changes are increased rate of respiration and ethylene production, loss of chlorophyll and continued expansion of cells and conversion of complex metabolites into simple molecules.

Table 2 Maturity indices for selected fruits and vegetables (Adapted from Dhatt and Mahajan 2007)

Fruits/vegetables	Maturity indices or characteristics
Almonds	Splitting of hull, separation of hull from shell, development of abscission zone
Apple	
'Golden Delicious'	12 % SSC, 18 lb firmness
'Red Delicious'	11 % SSC, 18 lb firmness
Banana	Disappearance of angularity in a cross section of the finger
Bear	Color break stage (when light yellow color appear)
Cherry	TSS = 14–15 %, light red color
Grapes (table)	Minimum SSC % of 14–17.5, depending on cultivars, SSC/TA of 20 or higher
Guava	Color break stage (when skin color changes from dark green to light green)
Lemon	30 % or more juice by volume
Litchi	TSS: total acid ratio of 30–40, bright red in color
Kiwi fruit	TSS – 6.5 %, Firmness = 14 lbs
Mango	Changes in shape (increase fullness of cheeks or bulge of shoulder), flesh color yellow to yellowish-orange
Papaya	Skin shows yellowing
Peach	Ground color change from green to yellow (varied for different cultivars)
Plums	Skin color changes
Pomegranate	Minimum 1.85 % TA and red juice color
Strawberry	2/3 of berry surface showing pink or red color
Beans	Pods are filled, seeds immature
Broccoli	Adequate diameter, compact, all florets should be closed
Cabbage	Firm head
Cantaloupe	¾ to full slip under slight pressure, abscission from vine
Carrot	Immature, roots reached adequate size
Cucumber	Immature and glossy skin
Garlic	Well filled bulbs, tops dry down
Ginger	8–9 months after planting
Melon	Ground color change to white with greenish tint, slightly waxy peel
Mushroom	Caps well rounded, partial veil completely intact
Okra	Pod 2–4″ long, not fibrous, tips of pods pliable
Onion (dry bulbs)	When 10–20 % of tops fall over
Peas	Pods well filled but not faded in color
Pepper	Fruit size and color (depends on color and intended market)
Potatoes	Harvest before vines die completely, cure to heal surface wounds
Radish (spring)	20–30 days after planting
Radish (winter)	45–70 days after planting
Tomato	Seeds fully developed, gel formation advanced in at least one locule
Watermelon	Flesh color 75 % red, TSS = 10 %

Source: Kitinoja and Gorny (1998)

Soluble solid content (*SSC*) also called total soluble solids (*TSS*), can be determined in a small sample of fruit juice using hand refractometer. Titratable acidity (*TA*) can be determined by titrating a know volume of juice with 0.1 N NaOH to end point of pink color as indicated by phenolphethalin indicator. The milliliters of NaOH needed are used to calculate the TA. The TA expressed as percent malic, citric or tartaric acid can be calculated as follows:

$$TA = \frac{\text{ml NaOH} \times \text{N(NaOH)} \times \text{acid meq. Factor}^{*} \times 100}{\text{Juice titrated}}$$

*The following acid meq. factor may be used for different fruits (for ex. for citric acid = 0.0064)

(v) **Senescence:** Senescence can be defined as the final phase in the ontogeny of the plant organ during which a series of essentially irreversible events occur which ultimately leads to cellular breakdown and death (Dhatt and Mahajan 2007).

Types of indices and their components:

(i) Visual indices (size, shape and color)
(ii) Physical indices (firmness and specific gravity)
(iii) Chemical measurement: Soluble Solids Content (SSC) or total soluble solids (TSS) and Titratable acidity (TA)
(iv) Calculated indices: calendar date and heat units (Dhatt and Mahajan 2007).

It could be concluded that, the stage of development at which a product is regarded as mature depends on its final use. Fruit and vegetables are eaten at all stages of development. We eat sprouted seeds, vegetative leaves and flowers, whole fruit as well as seeds and nuts. There are no general rules when it comes to defining horticultural maturity. It is worth to mention also that, the most important fruits and vegetables maturity indices are visual, physical, chemical and calculated indices.

2.3 Harvest Handling

Postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Postharvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product. The most important goals of postharvest handling are keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage. Sanitation is also an important factor, to reduce the possibility of pathogens that could be carried by fresh produce, for example, as residue from contaminated washing water. After the field, postharvest processing is usually continued in a packing house. This can be a simple shed, providing shade and running water, or a large-scale, sophisticated, mechanized facility, with conveyor belts, automated sorting and packing stations, walk-in coolers and the like. In mechanized harvesting, processing may also begin as part of the actual harvest process, with initial cleaning and sorting performed by the harvesting machinery (Simson and Straus 2010).

Postharvest handling is the final stage in the process of producing high quality fresh produce. Being able to maintain a level of freshness from the field to the dinner table presents many challenges. Production practices have a tremendous effect on the quality of fruits and vegetables at harvest and on postharvest quality and shelf life. It is well known that some cultivars ship better and have a longer shelf life than others. In addition, environmental factors such as soil type, temperature, frost, and rainy weather at harvest can have an adverse effect on storage life and quality. Management practices can also affect postharvest quality. Produce that has been stressed by too much or too little water, high rates of nitrogen, or mechanical injury (scrapes, bruises, abrasions) is particularly susceptible to postharvest diseases. Food safety also begins in the field, and should be of special concern, since a number of outbreaks of food borne illnesses have been traced to contamination of produce in the field. Harvest should be completed during the coolest time of the day, which is usually in the early morning, and produce should be kept shaded in the field. Handle produce gently. Crops destined for storage should be as free as possible from skin breaks, bruises, spots, rots, decay, and other deterioration. Bruises and other mechanical damage not only affect appearance, but provide entrance to decay organisms as well. The care taken during harvesting is repaid later, because fewer bruises and other injuries mean less disease and enhanced value. Good managers train their pickers so that they select the product at the correct stage of maturity with adequate care. It is worthwhile reducing the amount of hard physical work required in picking fruit and vegetables as far as possible. In recent years conveyors have been introduced for vegetable crops such as lettuce or celery and "cherry pickers" for tree crops. Such as increase the comfort and speed of harvesting and help the pickers to devote more energy to the care of the product (Jobling 2002).

It could be summarized the handling of vegetable and fruits postharvest as follows:

(A) Packing house operations

It is important to minimize mechanical damage by avoiding drops, rough handling and bruising during the different steps of pack house operations. Secondly the pack house operations should be carried out in shaded area. Shade can be created using locally available materials like, shade cloth, woven mats, plastic tarps or a canvas sheet hung from temporary poles. Shade alone can reduce air temperatures surrounding the produce by 8–17 °C. The packing house operations include the following steps:

(i) *Dumping*: The first step of handling is known as dumping. It should be done gently either using water or dry dumping. Wet dumping can be done by immersing the produce in water. It reduces mechanical injury, bruising, abrasions on the fruits, since water is more gentle on produce. The dry dumping is done by soft brushes fitted on the sloped ramp or moving conveyor belts. It will help in removing dust and dirt on the fruits.

(ii) *Pre-sorting*: It is done to remove injured, decayed, misshapen fruits. It will save energy and money because culls will not be handled, cooled, packed or transported. Removing decaying fruits are especially important, because these will limit the spread of infection to other healthy fruits during handling.

(iii) *Washing and cleaning:* Washing with chlorine solution (100–150 ppm) can also be used to control inoculums build up during pack house operations. For best results, the pH of wash solution should be between 6.5 and 7.5

(iv) *Sizing/grading*: Grading can be done manually or by automatic grading lines. Size grading can be done subjectively (visually) with the use of standard size gauges. Round produce units can be easily graded by using sizing rings (Dhatt and Mahajan 2007).

(B) Pre-cooling of horticulture produce

Pre-cooling of the produce soon after their harvest is one of the important components of the cool chain, which ultimately affect the shelf life of the produce. The main purpose of precooling is to immediately remove the field heat from the produce. It could be summarized the method of pre-cooling as follows:

I. *Room cooling*: It is low cost and slow method of cooling. In this method, produce is simply loaded into a cool room and cool air is allowed to circulate among the cartons, sacks, bins or bulk load.

II. *Forced air cooling*: Forced air-cooling is mostly used for wide range of horticultural produce. This is the fastest method of pre-cooling. Forced air-cooling pulls or pushes air through the vents/holes in storage containers. In this method uniform cooling of the produce can be achieved if the stacks of pallet bins are properly aligned. Cooling time depends on (i) the airflow, (ii) the temperature difference between the produce and the cold air and (iii) produce diameter.

III. *Hydrocooling*: The use of cold water is an old and effective cooling method used for quickly cooling a wide range of fruits and vegetables before packaging. For the packed commodities it is less used because of difficulty in the movement of water through the containers and because of high cost involved in water tolerant containers. This method of cooling not only avoids water loss but may even add water to the commodity. The hydrocooler normally used are of two types: shower and immersion type.

IV. *Vacuum cooling*: Vacuum cooling takes place by water evaporation from the product at very low air pressure. In this method, air is pumped out from a larger steel chamber in which the produce is loaded for pre-cooling. Removal of air results in the reduction of pressure of the atmosphere around the produce, which further lowers, the boiling temperature of its water. As the pressure falls, the water boils quickly removing the heat from the produce. Vacuum cooling cause about 1 % produce weight loss (mostly water) for each 6 °C of cooling.

V. *Package icing*: In some commodities, crushed or flaked ice is packed along with produce for fast cooling. However, as the ice comes in contact with the produce, it melts, and the cooling rate slows considerably. The ice keeps a high relative humidity around the product. Package ice may be finely crushed ice, flake ice or slurry of ice. Liquid icing distributes the ice throughout the container, achieving better contact with the product. Packaged icing can be used only with water tolerant, non-chilling sensitive products and with water tolerant packages such as waxed fiberboard, plastic or wood (Dhatt and Mahajan 2007).

(C) Postharvest treatments

Fresh fruits are living tissues subject to continuous change after harvest. Some changes are desirable from consumer point of view but most are not. Postharvest changes in fresh fruit cannot be stopped, but these can be slowed down within certain limits to enhance the shelf life of fruits. The post-harvest treatments play an important role in extending the storage and marketable life of horticultural perishables. The most important postharvest treatments include:

(i) ***Washing with chlorine solution***: Chlorine treatment (100–150 ppm available chlorine) can be used in wash water to help control inoculums build up during packing operations. Maintain pH of wash water between 6.5 and 7.5 for best results.

(ii) ***Ethylene inhibitors/Growth regulator/fungicide treatments***: 1-MCP (1-methyl cyclopropene), AVG (Amenoethoxyvinyl gycine), silver nitrate, silver thiosulfate, cycloheximide, benzothiadiazole etc. are some of the chemicals which inhibit ethylene production and/or action during ripening and storage of fruits. The growth regulators or fungicidal application such as GA_3 can be effectively used to extend/enhance the shelf life of fruits.

(iii) ***Calcium application***: The post-harvest application of $CaCl_2$ or Ca $(NO_3)_2$ play an important role in enhancing the storage and marketable life of fruits by maintaining their firmness and quality. Calcium application delays aging or ripening, reduces postharvest decay, controls the development of many physiological disorders and increases the calcium content, thus improving their nutritional value. The post-harvest application of $CaCl_2$ (2–4 %) or Ca $(NO_3)_2$ for 5–10 min dip extend the storage life of pear up to 2 months, plum up to 4 weeks and apple up to 6 months at 0–2 °C with excellent color and quality. Calcium infiltration reduces chilling injury and increase disease resistance in stored fruit.

(iv) ***Thermal treatments***: Thermal treatments included (a) hot water treatment: Fruits may be dipped in hot water before marketing or storage to control various post-harvest diseases and improving peel color of the fruit (Table 3). (b) Vapor heat treatment (VHT): This treatment proved very effective in controlling infection of fruit flies in fruits after harvest. The boxes are stacked in a room, which are heated and humidified by injection of steam.

Table 3 Hot water treatments for different fruits

Commodity	Pathogens	Temperature (°C)	Time (min)
Apple	*Gloeosporium* sp.	45	10
	Penicillium expansum		
Grapefruit	*Phytophthora citrophthora*	48	3
Lemon	*Penicillium digitatum*	52	5–10
	Phytophthora sp.		
Mango	*Collectotrichum gloeosporioides*	52	5
Orange	*Diplodia* sp.	53	5
	Phomopsis sp.		
	Phytophthora sp.		
Papaya	Fungi	48	20
Peach	*Monolinia fructicola*	52	2.5
	Rhizopus stolonifer		

Adapted from Kitinoja and Gorny (1998)

The temperature and exposure time are adjusted to kill all stages of insects (egg, larva, pupa and adult), but fruit should not be damaged. A recommended treatment for citrus, mangoes, papaya and pineapple is 43 ºC in saturated air for 8 h and then holding the temperature for further 6 h. VHT is mandatory for export of mangoes.

(v) ***Fumigation***: The fumigation of SO_2 is successfully used for controlling post-harvest diseases of grapes. This is achieved by placing the boxes of fruit in a gas tight room and introducing the gas from a cylinder to the appropriate concentration. However, special sodium metabisulphite pads are also available which can be packed into individual boxes of a fruit to give a slow release of SO_2. The primary function of treatment is to control the *Botrytis Cinerea*. The SO_2 fumigation is also used to prevent discoloration of skin of litchis.

(vi) ***Irradiation***: Ionizing radiation can be applied to fresh fruits and vegetables to control micro-organisms and inhibit or prevent cell reproduction and some chemical changes. It can be applied by exposing the crop to radiations from radioisotopes (normally in the form of gamma-rays measured in Grays (Gy), where 1 Gy = 100 rads.

(vii) ***Waxing***: Waxing of fruits or vegetables is a common post-harvest practice. Food grade waxes are used to replace some of the natural waxes removed during harvesting and sorting operations and can help reduce water loss during handling and marketing. It also helps in sealing tiny injuries and scratches on surface of fruits and vegetables. It improves cosmetic appearance and prolongs the storage life of fruits and vegetables. The wax coating must be allowed to dry thoroughly before packing (Dhatt and Mahajan 2007).

It could be concluded that, postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Postharvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product. The most important goals of postharvest handling are keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage.

2.4 Fruits and Vegetables Quality

Quality cannot be improved after harvest, only maintained; therefore it is important to harvest fruits, vegetables, and flowers at the proper stage and size and at peak quality. Quality is a complex perception of many attributes that are simultaneously evaluated by the consumer either objectively or subjectively. The brain processes the information received by sight, smell, and touch and instantly compares or associates it with past experiences or with textures, aromas, and flavors stored in its memory. For example, just by looking at the color, the consumer knows that a fruit is unripe and that it does not have

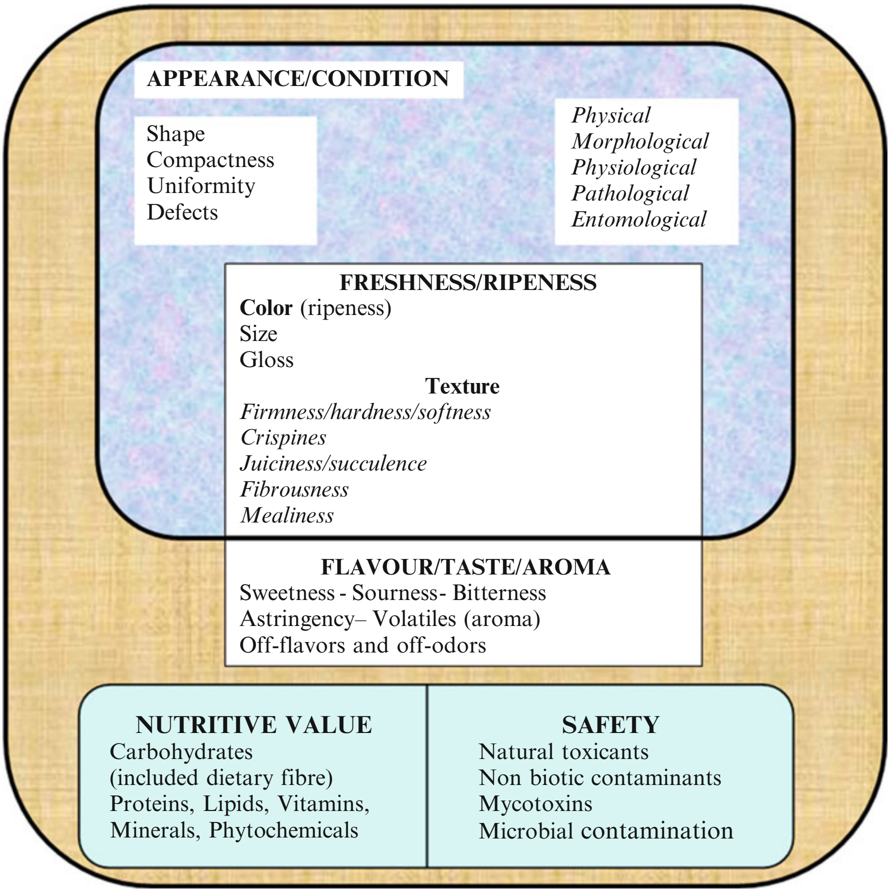

Fig. 3 Consumer perception of fruit and vegetable quality from nutritive value, safety to the physical properties of fruit and vegetable (Adapted from FAO 2004)

good flavor, texture or aroma. If color is not enough to evaluate ripeness, he/she uses the hands to judge firmness or other perceptible characteristics. The aroma is a less used parameter except in those cases where it is directly associated to ripeness like in melon or pineapple. This comparative process does not take place when the consumer sees for the first time an exotic fruit whose characteristics are unknown. Fruits and vegetables are consumed mainly for their nutritive value as well as for the variety of shapes, colors and flavors that make them attractive for food preparation. When they are consumed raw or with very little preparation, the consumer's main concern is that they must be free of biotic or non-biotic contaminants that may affect health (Figs. 3 and 4; FAO 2004).

The following tips can be followed for storage of high quality horticultural produce:

- Store only high quality produce, free of damage, decay and of proper maturity (not over-ripe or under-mature).
- Know the requirements for the commodities you want to put into storage, and follow recommendations for proper temperature, relative humidity and ventilation.

Fig. 4 Quality control of fruits is a constant challenge in food and life science industry with respect to contaminations and frauds like wrong labeling of the product type or the type and origin of ingredients. There are a lot of quality papmeters for fruits such as Brix analysis and juice quality (Photos by M. Fári in Cesena, Italy)

- Avoid lower than recommended temperatures in storage, because many commodities are susceptible to damage from freezing or chilling.
- Do not over load storage rooms or stack containers closely
- Provide adequate ventilation in the storage room.
- Keep storage rooms clean.
- Storage facilities should be protected from rodents by keeping the immediate outdoor area clean, and free from trash and weeds.
- Containers must be well ventilated and strong enough to with stand stacking. Do not stack containers beyond their stacking strength.
- Monitor temperature in the storage room by placing thermometers at different locations.
- Don't store onion or garlic in high humidity environments.
- Avoid storing ethylene sensitive commodities with those that produce ethylene.
- Avoid storing produce known for emitting strong odors (apples, garlic, onions, turnips, cabbages, and potatoes) with odor-absorbing commodities.
- Inspect stored produce regularly for signs of injury, water loss, damage and disease.
- Remove damaged or diseased produce to prevent the spread of problems (Dhatt and Mahajan 2007).

Fruit and vegetables are important sources of a wide range of vital micronutrients, phytochemicals and fibre, and there is now strong evidence that fruit and vegetable consumption can prevent a number of chronic non-communicable diseases, including cardiovascular diseases (CVD), diabetes, obesity, cancer and respiratory conditions (Robertson et al. 2004). Phytochemicals are bioactive non-nutrient plant compounds found in fruit, vegetables, grains and other plant foods that have been linked to reductions in the risk of major chronic diseases. They are almost ubiquitous in plant-derived foods and inherently have more subtle effects than nutrients. Phytochemicals can accumulate in relatively high amounts in plants and appear to have a myriad of supplemental roles in a plant's life cycle. Although these secondary metabolites account for the bioactive chemicals responsible for medicinal actions in humans, they are actually produced to provide the plant itself with unique survival or adaptive strategies. As sessile organisms, plants rely on the production of secondary compounds for defence, protection, cell-to-cell signaling and as attractants for pollinators. Phytochemicals can act as a 'shield' between plant tissues and the environment, thereby providing protection against abiotic stresses such as UV-B irradiation, temperature extremes, low water potential or mineral deficiency. One of the most versatile groups of phytochemicals in this regard, the anthocyanins, protect chloroplasts from photodegradation by absorbing high-energy quanta, while also scavenging free radicals and reactive oxygen species (Gould 2004). Flavonols, as well as providing protection against the damaging effects of UV-B, are also involved in promoting the growth of pollen tubes in the style to facilitate fertilization of the ovule. In addition, lignans, terpenoids and isoflavonoids play important defence roles against pathogen and insect attack (Table 4; Jaganath and Crozier 2008).

It could be concluded that, fruit and vegetables are important sources of a wide range of vital micronutrients, phytochemicals and fibre, and there is now strong evidence that fruit and vegetable consumption can prevent a number of chronic non-communicable diseases, including cardiovascular diseases, diabetes, obesity, cancer and respiratory conditions.

2.5 Preparation for the Fresh Market

After harvest, fruits and vegetables need to be prepared for sale. This can be undertaken on the farm or at the level of retail, wholesale or supermarket chain. Regardless of the destination, preparation for the fresh market comprises four basic key operations: (i) removal of unmarketable material, (ii) sorting by maturity and/or size, (iii) grading and (iv) packaging. Any working arrangement that reduces handling will lead to lower costs and will assist in reducing quality losses. Market preparation is therefore preferably carried out in the field. However, this is only really possible with tender or perishable products or small volumes for nearby markets. Products need to be transported to a packinghouse or packing shed for large operations, for distant or demanding markets or for special operations like washing, brushing, waxing, controlled ripening, refrigeration, storage or any specific type of treatment or

Table 4 List of fruit and vegetable (FAV) phytochemicals and major plant food sources

Phytochemicals		Major plant food sources
Carotenoids		Yellow, orange, red and green FAV. As a rule of thumb, the greater the intensity of the color of the fruit or vegetable, the more carotenoids it contains
	α-carotene, β-carotene, β-cryptoxanthin	Carrots, sweet potatoes, winter squash, pumpkin, papaya, mango, cantaloupe, oranges, broccoli, spinach, lettuce.
	Zeaxantine, Lutein	Green leafy vegetables such as spinach and kale.
	Lycopene	Tomatoes, watermelons, pink grapefruits, apricot, pink guavas.
Phenolics		
Phenolic acid		Seeds, berries, fruit and leaves of plants.
		Blueberries and other wild berries, dark plum, cherry, green and black teas, broccoli florets, olive oil.
Hydroxybenzoic acid	Gallic	Gallnuts, sumach, witch hazel, tea leaves, oak bark.
	Protocatechuic	Onion, roselle (*Hibiscus sabdariffa*)
	Vanillic	Vanilla.
	Syringic	Grapes.
Hydroxycinnamic acid	*p*-Coumaric	Wide variety of edible plants such as peanuts, tomatoes, carrots, garlic.
	Caffeic	Coffee beans.
	Ferulic	Seeds of plants such as brown rice, whole wheat and oats, coffee, apple, artichoke, peanut, orange, pineapple.
	Sinapic	All plants (lignin precursor).
Flavonoids		All citrus fruits, berries, onions, parsley, legumes, green tea, red grapes, red wine, dark chocolate.
Flavonols	Quercetin	Apples, green and black tea, onions (higher concentrations of quercetin occur in the outermost rings), red wine, red grapes, broccoli, leafy green vegetables, cherries and several wild berries (raspberries, bog whortleberries, cranberries, sweet rowan, rowanberries, sea buckthorn berries), prickly pear.
	Kaempferol	Green and black tea.
	Myricetin, Galangin, Fisetin	Grapes, berries, fruits, onions, broccoli, turnip, watercress.
Flavones	Apigenin, Chrysin, Luteolin	Celery, pepper, rutabagas, spinach.

(continued)

Table 4 (continued)

Phytochemicals		Major plant food sources
Catechins	Catechin, Epicatechin, Epigallocatechin	Apricot, berries, broad beans, peas, white tea, green tea, black tea, grapes and wine, oolong tea, peach, plums, strawberries, cocoa.
Flavanones	Eriodictyol, Hesperetin, Naringenin	Citrus fruits.
Anthocyanidins	Cyanidin, Pelargonidin, Peonidin	Red and blue FAV, blackberries, blueberries, hawthorn, raspberries, cranberries, elderberries, loganberries, strawberries and other berries, apples, cherry, plums (the highest concentrations of cyanidin are found in the skin of the fruit).
	Malvidin	Red and blue FAV (primarily responsible for the color of red wine).
	Delphinidin	Grape, blueberries, cranberries
Isoflavonoids	Genistein, Daidzein, Glycitein, Formonentin	Soybeans and soy products (tofu and textured vegetable protein) and, in small quantities, several other seeds.
Stilbenes	Resveratrol	Red grapes and red wine.
Coumarins		Notably woodruff and at lower levels in licorice.
Tannins		Tea, red grapes, red wine, pomegranates (punicalagins), persimmons, berries (cranberries, strawberries, blueberries).
Lignans		Flaxseeds (linseeds) and pulses, whole grain cereals, carrot, squash, sweet potatoes, green pepper, broccoli, garlic, asparagus, leek.
Alkaloids		Potatoes, tomatoes, cocoa, kola nut, guarana berries, tea plant, mushrooms.
Nitrogen containing compounds	Polyamines (spermidine, spermine, putrescine)	Fruits (with exception of berries) and fruity vegetables (tomatoes, eggplants), potatoes, cereal germ.
Organosulfur compounds	Isothiocyanates, Indoles	Cruciferous vegetables, broccoli, cabbage, cauliflower, kale, turnips, collards, brussels sprouts, radish, turnip, watercress
	Allylic sulfur compounds	Garlic.
Vitamin C		Citrus fruits (orange, lemon, grapefruit, lime), strawberries, cranberries, blackcurrants, papaya, kiwifruit, tomatoes, potatoes, broccoli, brussels sprouts, cauliflower, spinach, cantaloupe, red peppers.

(continued)

Table 4 (continued)

Phytochemicals		Major plant food sources
Vitamins B	Thiamine (B_1)	Green peas, spinach, navy beans, nuts, pinto beans, soybeans, whole-grain cereals, breads, pulses.
	Riboflavin (B_2)	Leafy green vegetables, legumes, almonds.
	Pantothenic acid (B_5)	High amounts in whole-grain cereals and pulses.
	Pyridoxine (B_6)	Lima beans, peanuts, whole-grain cereals, avocado, bananas, dragon fruit.
	Cyanocobalamin ($B1_2$)	Seaweeds (nori), barley grass.
Folic acid		Leafy vegetables such as spinach and turnip greens, dried beans and peas, sunflower seeds and certain other FAV.
Vitamin E (tocopherol)		Vegetable oils such as palm, olive, sunflower, soybean and corn, nuts, sunflower seeds, seabuckthorn berries, kiwi fruit, wheat germ.

Adapted from Jaganath and Crozier (2008)

packaging. These two systems (field vs. packinghouse preparation) are not mutually exclusive. In many cases partial field preparation is completed later in the packing shed. Because it is a waste of time and money to handle unmarketable units, primary selection of fruits and vegetables is always carried out in the field where products with severe defects, injuries or diseases are removed. Field preparation of lettuce is an example where a team of three workers cut, prepare and pack. For distant markets, boxes prepared in the field are delivered to packinghouses for palletizing, pre-cooling, and sometimes cold storage before shipping. Mobile packing sheds provide an alternative for handling large volumes in limited time. Harvest crews feed a mobile grading and packing line. On completion of loading, the consignment is shipped to the destination market. In mechanized harvesting, the product is transported to the packinghouse where it is prepared for the market. In many cases, harvest crews make use of an inspection line for primary selection in the field (Simson and Straus 2010).

Preparation and packing operations should be designed to minimize the time between harvest and delivery of the packaged product. Delays frequently occur in the reception area; therefore the produce should be protected from the sun as much as possible. Produce is normally weighed or counted before entering the plant and, in some cases; samples for quality analysis are taken. Records should be kept, particularly when providing a service to other producers. Preparation for the fresh market starts with dumping onto packinghouse feeding lines. Dumping may be dry or in water. In both cases it is important to have drop decelerators to minimize injury as well as to control the flow of produce. Water dipping produces less bruising and can be used to move free-floating fruits; however, not all products tolerate wetting. Products with a specific density lower than water will float. Salts e.g. sodium sulphate are diluted in the water to improve the flotation of other products. Water dipping through washing helps to remove most dirt from the field. For thorough cleaning, more washing and brushing are required. Water rinsing allows produce to maintain cleanliness and be free of soil, pesticides, plant debris and rotting parts. However, in some cases this is not possible because of insufficient water. If recycled water is used, it needs to be filtered and the settled dirt removed. Chlorination of dumping and washing waters with a concentration of 50–200 ppm active chlorine eliminates fungi spores and bacteria on the surface of diseased fruits, which prevents the contamination of healthy fruit. Bruising should be avoided because it creates the entry for infection by decay organisms. At depths greater than 30 cm and for periods of immersion longer than 3 min, water tends to penetrate inside fruits, particularly those that are hollow, for example, peppers. Water temperature also contributes to infiltration. It is recommended that the temperature of fruit is at least 5 °C lower than that of water (FAO 2004).

It could be concluded that, fruits and vegetables need to be prepared for sale after harvest and this can be undertaken on the farm or at the level of retail, wholesale or supermarket chain. Regardless of the destination, preparation for the fresh market comprises four basic key operations i.e., removal of unmarketable material, sorting by maturity and/or size, grading and packaging. Preparation and packing operations should be designed to minimize the time between harvest and delivery of the packaged product.

2.5.1 Packaging

Packaging is the act of putting the produce inside a container along with packing materials to prevent movement and to cushion the produce such as plastic or moulded pulp trays, inserts, cushioning pads, etc. and to protect it i.e., plastic films, waxed liners, etc. Packaging must satisfy three basic objectives: (i) contain product and facilitate handling and marketing by standardizing the number of units or weight inside the package. (ii) Protect product from injuries (impact, compression, abrasion and wounds) and adverse environmental conditions (temperature, relative humidity) during transport, storage and marketing. (iii) Provide information to buyers, such as variety, weight, number of units, selection or quality grade, producer's name, country and area of origin. Frequently included are recipes, nutritional value, bar codes or any other relevant information on traceability. A well-designed package needs to be adapted to the conditions or specific treatments required for the product (Fig. 5). If hydro-cooling or ice-cooling is required, the package must tolerate wetting without losing strength. For a product with a high respiratory rate, the packaging should have sufficiently large openings to allow good gas exchange. When produce dehydrates easily, the packaging should be designed to provide a good barrier against water loss, etc. Semi-permeable materials make it possible to generate special atmospheres inside packages. This helps in maintaining produce freshness. There are three types of packaging: (1) consumer units or prepackaging, (2) transport packaging and (3) unit load packaging or pallets (FAO 2004).

Fig. 5 Some vegetables in the final package in the super market and ready for consumers (Photos by M. Fári in China)

Fresh fruits and vegetables are generally packed in bamboo baskets, plastic crates, plastic bags, or nylon sacks for transportation, in many developing countries. Often, they are transported in an unpackaged form. After harvest, fresh fruits and vegetables are generally transported from the farm to either a packing house or distribution center. Farmers sell their produce either in fresh markets or in wholesale markets. At the retail level, fresh produce is sold in an unpackaged form, or is tied in bundles. This type of market handling of fresh produce greatly reduces its shelf life if it is not sold quickly. The application of proper postharvest technologies, would, however, extend postharvest shelf life, retain fresh quality and reduce losses. Packaging plays a very important role in protecting fresh produce:

- It provides protection from dust;
- It reduces microbial contamination from the surrounding environment and from consumer contact;
- It helps to maintain the freshness of produce;
- It extends the postharvest shelf life;
- It increases the sale of fresh produce.

The following are among the more important general requirements and functions of food packaging materials/containers: (a) they must be non-toxic and compatible with the specific foods; (b) sanitary protection; (c) moisture and fat protection; (d) gas and odor protection; (e) light protection; (f) resistance to impact; (g) transparency; (h) ease of opening; (i) pouring features; (j) reseal features; (k) ease of disposal; (l) size, shape, weight limitations; (m) appearance, printability; (n) low cost and (o) special features (Simson and Straus 2010).

Films and foils have different values for moisture and gas permeability, strength, elasticity, inflammability and resistance to insect penetration and many of these characteristics depend upon the film's thickness. Important characteristics of the types of films and foils commonly used in food packaging are given in Table 5.

The development of packaging which is suited to the handling of fresh produce necessitates an understanding of the physiological characteristics of the produce. Fruits and vegetables may be characterized as being either climacteric or non-climacteric, depending on their respiratory pattern (Fig. 6):

- *Non-climacteric fruit* ripen only while still attached to the parent plant. Their eating quality suffers if they are harvested before they are fully ripe because their sugar and acid contents do not increase further. Their respiration rate gradually declines during growth and after harvesting. Maturation and ripening are a gradual process. Examples of non-climacteric fruit include: cherries, cucumbers, grapes, lemons and pineapples (Sirivatanapa 2006).
- *Climacteric fruit* can be harvested when mature but before the onset of ripening. These fruits may undergo either natural or artificial ripening. The onset of ripening is accompanied by a rapid rise in respiration rate, generally referred to as the respiratory climacteric. After the climacteric, the respiration rate slows down as the fruit ripens and develops good eating quality. Examples of climacteric fruit include: apples, bananas, melons, papaya and tomatoes (Sirivatanapa 2006).

Table 5 Properties of packaging films

Material	Properties
Paper	Strength; rigidity; opacity; printability.
Aluminum foil	Negligible permeability to water-vapor, gases and odors; grease proof, opacity and brilliant appearance; dimensional stability; dead folding characteristics.
Cellulose film (coated)	Strength; attractive appearance; low permeability to water vapor (depending on the type of coating used), gases, odors and greases; printability.
Polythene	Durability; heat-sealability; low permeability to water-vapor; good chemical resistance; good low-temperature performance.
Rubber hydrochloride	Heat-sealability;. low permeability to water vapor, gases, odors and greases; chemical resistance.
Cellulose acetate	Strength; rigidity; glossy appearance; printability; dimensional stability.
Vinylidene chloride	Low permeability to water vapor, gases, copolymer odors and greases; chemical resistance; heat-sealability.
Polyvinyl chloride	Resistance to chemicals, oils and greases; heat-sealability.
Polyethylene terephtalate	Strength; durability; dimensional stability; low permeability to gases, odors and greases.

Adapted from Simson and Straus (2010)

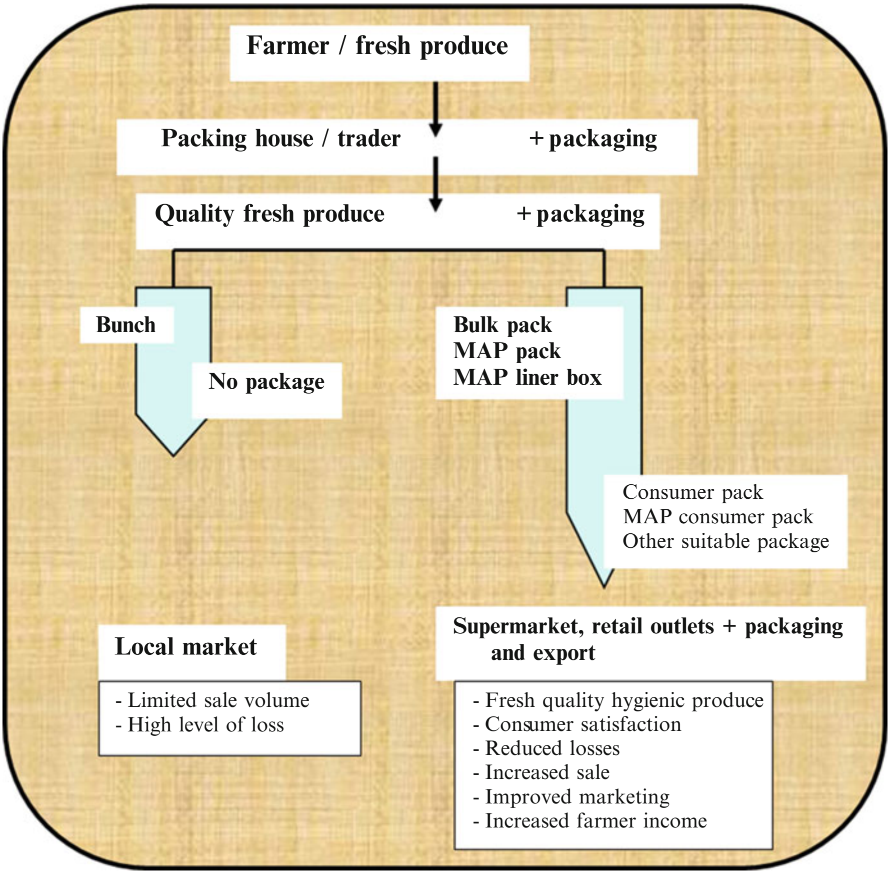

Fig. 6 Packaging and transportation of fruits and vegetables to local or supermarket. MAP is modified atmospheric package (Adapted from Sirivatanapa 2006)

Therefore, it could be concluded that, packaging is the act of putting the produce inside a container along with packing materials to prevent movement. Packaging must satisfy three basic objectives: (i) contain product and facilitate handling and marketing by standardizing the number of units or weight inside the package. (ii) Protect product from injuries and adverse environmental conditions during transport, storage and marketing. (iii) Provide information to buyers, such as variety, weight, number of units, selection or quality grade, producer's name, country and area of origin.

2.6 Storage Process

Without doubt, the ability to store harvested plant organs for extended periods of time has played a critical role in the development of agriculture. Simple baskets were used as early as 7000 BC to gather and store food until consumed. Advances in technology such as fired clay pottery would enable primitive societies to store crops in concealed environments, creating a simple modified atmosphere. Middle Eastern artisans specialized in making pottery of numerous shapes and sizes for varied usage (ca. 4500 BC), while pre-Neolithic, Middle Eastern societies held grain in underground pits 9,000–11,000 years ago. Ancient Egyptians and Samarians are thought to have stored some of their crops in sealed limestone crypts to prolong storage life about 2500 BC. Pits were and are still used by primitive societies for storing various types of fruits and vegetables. Silos for long-term grain storage were used by the Romans and continued to be popular until well into the nineteenth century. Ancient (and modern) people often dried fruits such as apples, apricots, figs, and grapes to prolong the storage longevity of these perishable crops (De Long and Prange 2003).

In temperate areas most fruit and vegetable production is seasonal. In contrast, cultivation and harvest periods are much longer in tropical and subtropical areas. Demand is year round and it is normal practice to use storage in order to ensure continuity of supply. Storage is also used as a strategy for achieving higher returns. Produce can be held temporarily to overcome gluts thus limiting price falls or to address shortage periods when prices are high. Storage time depends on the intrinsic characteristics and perishability of the product. Shelf life ranges from short periods for products such as raspberries and other berries to long periods for products such as onions, potatoes, garlic and pumpkins. Storage conditions also depend on specific product characteristics. For example, leafy vegetables tolerate temperatures close to 0 °C, while most tropical fruits cannot tolerate exposure to temperatures below 10 °C. In order to optimize storage conditions, only one crop should be stored in a room unless it is for a short period of time. Using the same storage area for different products can result in product damage because of incompatibility of temperature and relative humidity conditions, chilling and ethylene sensitivity, odor contamination and other problems affecting shelf life and quality. Generally, storage facilities are linked or integrated to packinghouses or other areas where there is a concentration of produce. However, often produce can be stored on farm, either naturally or in specifically designed facilities. Location and design have an impact on system operations and efficiency even when mechanical refrigeration is used. Climate is an important factor for the location of the storage facility. For example, altitude reduces temperature by 10 °C for every 1,000 m of elevation. It also increases the overall efficiency of refrigeration equipment by facilitating heat exchange with ambient temperature, thereby reducing energy costs. Shading, particularly of loading and unloading areas, reduces thermal differences between field and storage temperatures (Tables 6 and 7; FAO 2004).

Therefore, it could be concluded that, the ability to store harvested plant organs for extended periods of time has played a critical role in the development of agriculture. Ancient Egyptians and Samarians are thought to have stored some of their crops in

Table 6 Maximum storage life (days) in normal atmosphere storage (NA), controlled atmosphere (CA) and low-pressure storage (LP)

Commodity	Maximum storage time (days)		
	Normal atmosphere storage	Controlled atmosphere	Low-pressure storage
Apple (various)	200	300	300
Asparagus	14–21	Slight benefit – off-odors	28–42
Avocado (Lula)	30	42–60	102
Banana	14–21	42–56	150
Carnation (flower)	21–42	No benefit	140
Cherry (sweet)	14–21	28–35	56–70
Cucumber	9–14	14+ (slight benefit)	49
Green pepper	14–21	No benefit	50
Lime (Persian)	14–28	Juice loss, peel thickens	90
Mango (Haden)	14–21	No benefit	42
Mushroom	5	6	21
Papaya (Solo)	12	12+ (slight benefit)	28
Pear (Bartlett)	60	100	200
Protea (flower)	< 7	No benefit	30
Rose (flower)	7–14	No benefit	42
Spinach	10–14	Slight benefit	50
Strawberry	7	7+ (off-flavor)	21
Tomato (mature-green)	7–21	42	84

Adapted from Burg (2004)

To simplify comparisons between results obtained at atmospheric and sub-atmospheric pressures, the O_2, CO_2 and NH_3 concentrations are expressed as percent [O_2], [CO_2] and [NH_3], where 2 % [O_2] refers to an O_2 partial pressure of 0.02 atm. According to international conventions, the pressure-unit conversion constants are: 1 atm (standard) = 101.33 kPa (kilopascals) = 1013.3 mbar (millibar) = 760 mm Hg (mm mercury) = 760 Torr = 14.696 psi (lb in^{-2})

Table 7 The most important different methods of cooling

Method	Details
Precooling	Precooling is the rapid reduction of field temperature prior to processing, storage, or refrigerated transport. Generally it is a separate operation requiring special facilities, but complementary to cold storage. As deterioration is proportional to the time produce is exposed to high temperatures, precooling is beneficial even when produce is later returned to ambient conditions. It is critical in maintaining the quality of fruits and vegetables and forms part of the "cold chain" to maximize postharvest life.
Room cooling	Room cooling is the most widely used system and is based on the product's exposure to cold air inside a refrigerated room. It is simple to operate as the product is cooled and stored in the same room. However, the slow removal of heat makes this system unsuitable for highly perishable commodities because at least 24 h is needed to reach the required storage temperature. Almost all other crops are suitable for this type of cooling; however, it is mainly used for potatoes, onions, garlic, citrus, etc.
Forced-air cooling	Cold air is forced to pass through produce by means of a pressure gradient across packages. Cooling is four to ten times more rapid than room cooling and its rate depends on airflow and the individual volume of produce.
Hydrocooling	The refrigerating medium for hydrocooling is cold water. Because of its higher capacity to absorb heat, it is faster than forced-air cooling. Hydrocooling can be achieved by immersion or through means of a chilled water shower. In the latter case produce must be arranged in thin layers for uniform cooling. This system cannot be used for crops that do not tolerate wetting, chlorine and water infiltration. Tomatoes, asparagus and many other vegetables are hydrocooled commercially. Chlorination of water (150–200 ppm) is important to prevent the accumulation of pathogens.
Ice cooling	Ice cooling is probably one of the oldest methods used to reduce field temperature. It is most commonly used for individual packages – crushed ice is placed on top of the produce before the package is closed. Ice layers may also be interspersed with produce. As it melts, cold water cools the lower layers of produce. Liquid icing is another system where a mix of water and crushed ice (40 % water + 60 % ice + 0.1 % salt) is injected into open containers so that a big ice block is formed. The main disadvantage of ice cooling is that it is limited to ice-tolerant crops. It also increases costs because of the heavier weight for transportation and the need for oversized packages. Another disadvantage is that as water melts, storage areas, containers and shelves become wet.
Evaporative	This is one of the simplest cooling systems. It involves forcing dry air through wet products. Heat is absorbed from the product as water evaporates. This method has a low energy cost but cooling efficiency is limited by the capacity of air to absorb humidity.
Vacuum cooling	Vacuum cooling is one of the more rapid cooling systems; however, cooling is accomplished at very low pressures. At a normal pressure of 760 mmHg, water evaporates at 100 °C, but it evaporates at 1 °C if pressure is reduced to 5 mmHg. Produce is placed in sealed containers where vacuum cooling is performed. This system produces about 1 % product weight loss for each 5 °C of temperature reduction. Modern vacuum coolers add water as a fine spray in the form of pressure drops. Similar to the evaporation method, this system is in general appropriate for leafy vegetables because of their high surface-to-mass ratio.

Adapted from FAO (2004)

sealed limestone crypts to prolong storage life about 2500 BC. In order to optimize storage conditions, only one crop should be stored in a room unless it is for a short period of time. Using the same storage area for different products can result in product damage because of incompatibility of temperature and relative humidity conditions, chilling and ethylene sensitivity, odor contamination and other problems affecting shelf life and quality.

2.7 Storage Systems

The marketable life of most fresh vegetables 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. Storage rooms can be grouped accordingly as those requiring refrigeration and those that do not. Storage rooms and methods not requiring refrigeration include: *in situ*, sand, coir, pits, clamps, windbreaks, cellars, barns, evaporative cooling, and night ventilation as follows:

1. ***In situ:***
   This method of storing fruits and vegetables involves delaying the harvest until the crop is required. It can be used in some cases with root crops, such as cassava, but means that the land on which the crop was grown will remain occupied and a new crop cannot be planted. In colder climates, the crop may be exposed to freezing and chilling injury.
2. ***Sand or coir:***
   This storage technique is used in countries like India to store potatoes for longer periods of time, which involves covering the commodity under ground with sand.
3. ***Pits or trenches:***
   Pits are dug at the edges of the field where the crop has been grown. Usually pits are placed at the highest point in the field, especially in regions of high rainfall. The pit or trench is lined with straw or other organic material and filled with the crop being stored, then covered with a layer of organic material followed by a layer of soil. Holes are created with straw at the top to allow for air ventilation, as lack of ventilation may cause problems with rotting of the crop.
4. ***Clamps:***
   This has been a traditional method for storing potatoes in some parts of the world, such as Great Britain. A common design uses an area of land at the side of the field. The width of the clamp is about 1–2.5 m. The dimensions are marked out and the potatoes piled on the ground in an elongated conical heap. Sometimes straw is laid on the soil before the potatoes. The central height of the heap depends

on its angle of repose, which is about one third the width of the clump. At the top, straw is bent over the ridge so that rain will tend to run off the structure. Straw thickness should be from 15 to 25 cm when compressed. After 2 weeks, the clamp is covered with soil to a depth of 15–20 cm, but this may vary depending on the climate.

5. ***Windbreaks:***
   Windbreaks are constructed by driving wooden stakes into the ground in two parallel rows about 1 m apart. A wooden platform is built between the stakes about 30 cm from the ground, often made from wooden boxes. Chicken wire is affixed between the stakes and across both ends of the windbreak. This method is used in Britain to store onions.
6. ***Cellars:***
   These underground or partly underground rooms are often beneath a house. This location has good insulation, providing cooling in warm ambient conditions and protection from excessively low temperatures in cold climates. Cellars have traditionally been used at domestic scale in Britain to store apples, cabbages, onions, and potatoes during winter.
7. ***Barns:***
   A bam is a farm building for sheltering, processing, and storing agricultural products, animals, and implements. Although there is no precise scale or measure for the type or size of the building, the term bam is usually reserved for the largest or most important structure on any particular farm. Smaller or minor agricultural buildings are often labeled sheds or outbuildings and are normally used to house smaller implements or activities.
8. ***Evaporative cooling:***
   When water evaporates from the liquid phase into the vapor phase energy is required. This principle can be used to cool stores by first passing the air introduced into the storage room through a pad of water. The degree of cooling depends on the original humidity of the air and the efficiency of the evaporating surface. If the ambient air has low humidity and is humidified to around 100 % RH, then a large reduction in temperature will be achieved. This can provide cool moist conditions during storage.
9. ***Night ventilation:***
   In hot climates, the variation between day and night temperatures can be used to keep stores cool. The storage room should be well insulated when the crop is placed inside. A fan is built into the store room, which is switched on when the outside temperature at night becomes lower than the temperature within. The fan switches off when the temperatures equalize. The fan is controlled by a differential thermostat, which constantly compares the outside air temperature with the internal storage temperature. This method is used to store bulk onions (Simson and Straus 2010).

There are many ways of storing a product. The length of storage time can be longer in specifically designed structures. With refrigeration and controlled atmospheres, storage periods can be even longer. The technology utilized depends on whether the benefits i.e., higher prices outweigh the costs. The most important storage systems are as follows:

(I) Natural or field storage:

This is the most rudimentary system and is still in use for many crops such as roots such as carrots, sweet potatoes, and cassava and tubers (potatoes). Crops are left in the soil until preparation for the market. This is similar to the way citrus and some other fruits are left on the tree.

(II) Natural ventilation:

Amongst the wide range of storage systems, natural ventilation is the simplest. It takes advantage of the natural airflow around the product to remove the heat and humidity generated by respiration. Structures that provide some form of protection from the external environment and gaps for ventilation can be used. Produce is placed in bulk, bags, boxes, bins, pallets, etc. Although natural storage is widely practiced, it leaves products exposed to pests and diseases as well as to adverse weather conditions that can have a detrimental effect on quality. Although simple, some key concepts must be taken into account for the efficient operation of this system:

- Differences in internal temperature and relative humidity conditions compared with external conditions need to be minimal. This system can only be used with crops that store well under natural conditions such as potatoes, onions, sweet potatoes, garlic and pumpkins.
- Openings need to be wide for adequate ventilation and they should be fitted with screens to keep out animals, rodents and pests.
- As with fluids, air follows the path of least resistance. If produce is stored in a compact mass, air will circulate to remove heat and gases that have accumulated as a result of respiration. Efficient ventilation requires adequate space; however, this reduces storage capacity.
- Hot and humid air rises within the storage facility. If no ventilation gaps exist, hot and humid areas build up, which in turn affect the quality of stored goods and create ideal conditions for the development of disease.

(III) Forced-air ventilation:

Heat and gas exchange can be improved provided air is forced to pass through the stored produce. This system allows for more efficient utilization of space for bulk storage. Air conducts run under a perforated floor and air is forced through the produce. As air follows the path of least resistance, loading patterns as well as fan capacity and conduct dimensions should be carefully calculated to ensure that there is uniform distribution of air throughout the stored produce.

(IV) Refrigeration:

Refrigeration is the most widely used method for extending the postharvest life of fruits and vegetables and temperature control is one of the main tools for extending postharvest life. Low temperatures slow product metabolism and the activity of microorganisms responsible for quality deterioration. As a result, reserves are maintained with a lower respiration rate, ripening is retarded and vapor pressure between products and ambient is minimized reducing water loss. These factors contribute towards maintaining freshness by reducing the rate at which quality deteriorates and the nutritional value of the product is preserved. A refrigerated room is a relatively airtight and thermally insulated environment. The refrigeration equipment should have an external escape outlet to release the heat generated by the product. Refrigeration capacity of the equipment should be adequate to extract the heat generated by crops with a high respiration rate. It is also important to control precisely the temperature and relative humidity conditions inside the refrigerated storage environment. It could be concluded the different methods of cooling in Table 8 and the different crop according to cooling method in Table 9.

Therefore, it could be concluded that, the marketable life of most fresh vegetables 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. Storage rooms can be grouped accordingly as those requiring refrigeration and those that do not. Storage rooms and methods not requiring refrigeration include: *in situ*, sand, coir, pits, clamps, windbreaks, cellars, barns, evaporative cooling, and night ventilation. The length of storage time can be longer in specifically designed structures. With refrigeration and controlled atmospheres, storage periods can be even longer. The technology utilized depends on whether the benefits i.e., higher prices outweigh the costs.

2.8 Hygiene and Sanitation

Sanitation is of great concern to produce handlers, not only to protect produce against postharvest diseases, but also to protect consumers from food borne illnesses. *E. coli* 0157:H7, *Salmonella, Chryptosporidium, Hepatitis,* and *Cyclospera* are among the disease-causing organisms that have been transferred via fresh fruits and vegetables. Use of a disinfectant in wash water can help to prevent both postharvest diseases and food borne illnesses. The different stages of operations that a product goes through after harvest provide many occasions for contamination besides those that naturally occur in the field. Consumers strongly reject foreign materials on products or inside packages, such as dirt, animal feces, grease or lubricating oil, human hairs, insects and plant debris (Fig. 7).

However, because this type of contamination is usually caused by insufficient care in handling, it is relatively easy to detect and to eliminate. A more serious problem is the presence of human pathogens on produce. These may not be visible or detected because of changes in appearance, flavor, color or other external characteristics. It has been shown that specific pathogens are able to survive on produce sufficiently long to constitute a threat. In fact, many cases of illness related to consumption of produce have been reported. Three types of organisms that can be transported on fruits and vegetables may

Table 8 Classification of crops according to cooling method

Room cooling	Forced-air cooling	Hydrocooling	Ice cooling	Vacuum cooling
Artichoke	Avocado	Artichoke	Belgian endive	Belgian endive
Banana	Banana	Asparagus	Broccoli	Brussels sprouts
Beans (dry)	Barbados cherry	Beet	Brussels sprouts	Carrot
Beet	Berries	Belgian endive	Cantaloupe	Cauliflower
Breadfruit	Brussels sprouts	Broccoli	Chinese cabbage	Chinese cabbage
Cabbage	Cactus leaves	Brussels sprouts	Carrot	Celery
Cactus leaves	Cassava	Cantaloupe	Escarole	Escarole
Cassava	Coconut	Cauliflower	Green onions	Leek
Coconut	Cucumber	Carrot	Kohlrabi	Lettuce
Custard apple	Eggplant	Cassava	Leek	Lima bean
Garlic	Fig	Celery	Parsley	Mushrooms
Ginger	Ginger	Chinese cabbage	Pea/snow peas	Snap beans
Grapefruit	Grape	Cucumber	Spinach	Snow peas
Horse radish	Grapefruit	Eggplant	Sweet corn	Spinach
J. artichoke	Guava	Escarole	Swiss chard	Sweet corn
Kohlrabi	Kiwi fruit	Green onions	Watercress	Swiss chard
Kumquat	Kumquat	Horse radish		Watercress
Lime	Lima bean	J. artichoke		
Lemon	Mango	Kiwi fruit		
Melons	Melons	Kohlrabi		
Onion	Mushrooms	Leek		
Orange	Okra	Lima bean		
Cucumber	Orange	Orange		
Pineapple	Papaya	Parsley		
Potato	Passion fruit	Parsnip		
Pumpkin	Pepper (Bell)	Peas		
Radish	Pineapple	Pomegranate		
Summer squash	Pomegranate	Potato (early)		
Sweet potato	Prickly pear	Radish		
Tomato	Pumpkin	Snap beans		
Turnip	Snap beans	Snow peas		
Watermelon	Snow peas	Spinach		
	Strawberry	Summer squash		
	Summer squash	Sweet corn		
	Tangerine	Swiss chard		
	Tomato	Watercress		

Adapted from Sargent et al. (2000)

constitute a risk to human health: virus e.g. hepatitis A, bacteria e.g. *Salmonella* spp., *Escherichia coli*, *Shigella* spp. and parasites e.g. *Giardia* spp. Mycotoxins and fungi do not usually constitute a problem because fungi development is usually detected and eliminated well before the formation of mycotoxins (FAO 2004).

Table 9 Potential risks of microbial contamination and recommended preventive measures

Production step	Risks	Prevention
Production field	Animal fecal contamination	Avoid animal access, either wild, production or even pets.
Fertilizing	Pathogens in organic fertilizers	Use inorganic fertilizers.
		Proper composting
Irrigation	Pathogens in water	Underground drip irrigation
		Check microorganisms in water
Harvest	Fecal contamination	Personal hygiene. Portable bathrooms.
		Risk awareness
	Pathogens in containers and tools	Use plastic bins. Cleaning and disinfecting tools and containers
Packhouse	Fecal contamination	Personal hygiene. Sanitary facilities. Avoid animal entrance. Eliminate places may harbor rodents.
	Contaminated water	Alternative methods for precooling. Use potable water. Filtration and chlorination of recirculated water. Multiple washing
Storage and transportation	Development of microorganisms on produce	Adequate temperature and relative humidity. Watch conditions inside packaging. Cleaning and disinfection of facilities. Avoid repackaging. Personal hygiene. Do not store or transport with other fresh products. Use new packing materials
Sale	Product contamination	Personal hygiene. Avoid animal access.
		Sell whole units. Cleaning and disinfection of facilities. Discard garbage daily.

Adapted from FAO (2004)

In most cases, bacteria are responsible for illnesses related to the consumption of fruits and vegetables. Some human pathogens are naturally present in the environment. However, fecal deposits (human as well as from domestic and wild animals) are the main source of contamination of produce. Entry is mainly through irrigation or washing water. Microorganisms in surface water (rivers, lakes, etc.) may come from the upstream dumping of untreated municipal wastes. Underground water may also be contaminated from septic tanks leaching through soil into aquifers. If only contaminated water is available, underground drip irrigation is the only irrigation system recommended to avoid the contamination of above-ground edible plants. The main causes of contamination are the use of animal manure or sewage waste as organic fertilizer and the presence of animals in production areas. Manure should be composted aerobically to reach between 60 and 80 °C for a minimum of 15 days. Composting of static piles and earthworms do not guarantee that microorganisms have been inactivated. Wastewater and municipal wastes should only be used if effective disinfecting systems are available (FAO 2004).

Therefore, it could be concluded that, sanitation is of great concern to produce handlers, not only to protect produce against postharvest diseases, but also to protect consumers from food borne illnesses. Use of a disinfectant in wash water can help to prevent both postharvest diseases and food borne illnesses.

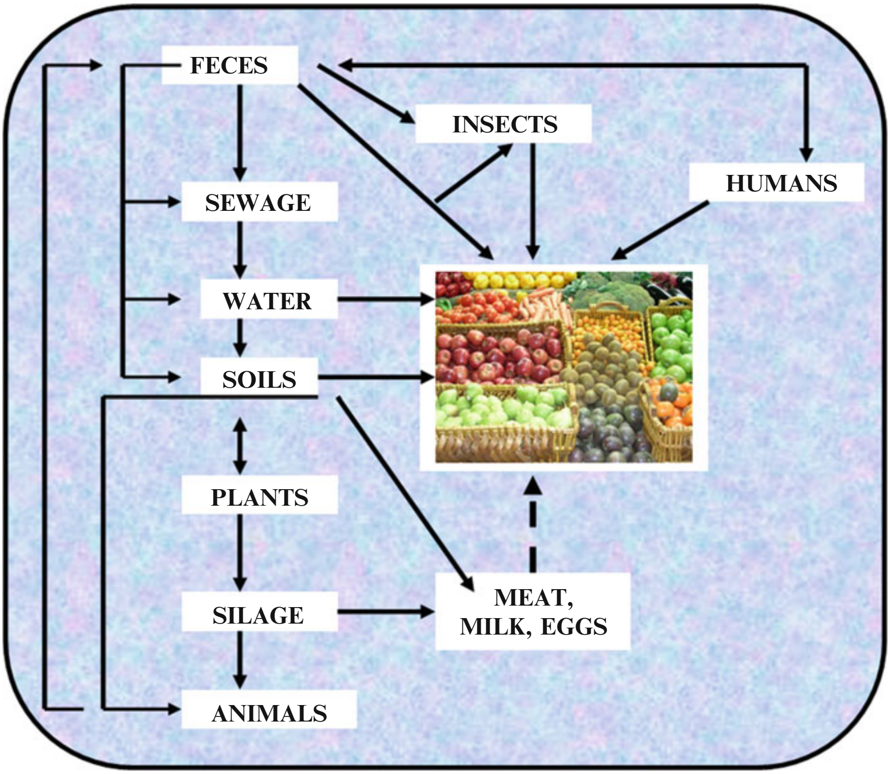

Fig. 7 Mechanisms by which fruit and vegetable can become contaminated with pathogenic microorganisms (Adapted from Harris 1998)

3 Influence of Preharvest Factors on Postharvest Quality

Preharvest factors greatly influence both the condition of the crop at harvest and the crop's storage and nutritive potential. The postharvest quality of fresh horticultural commodities markedly depends upon the quality attained at the time of harvest. Many preharvest factors are known to affect storage quality, including: genotype and cultivar selection; stage of maturity when harvested; climatic conditions such as temperature, light intensity, and rainfall amounts; soil texture and fertility; fertilizer type and application rates; disease and insect pressure; and growth regulator and pesticide application. Evaluating which preharvest conditions exert the most influence on postharvest fruit quality is difficult as they interact during the growing season and can change in degree of influence from year to year. Nonetheless, the goal in managing preharvest factors is ultimately to harvest the crop at the highest degree of quality and to sustain that quality throughout the storage period (De Long and Prange 2003).

The harvest of any crop, whether fruit, vegetable, or flower, is associated with mechanical stresses and because the plant part is separated from the parent, removal from a supply of water, nutrients, hormones, and energy. When harvested, the plant part has an altered ability to respond to stresses in the environment. Stress interrupts, restricts, or accelerates normal metabolic processes in an adverse or negative manner, and therefore is usually considered as potentially injurious to any plant system. However, consideration of postharvest systems is complicated as many storage regimens beneficially utilize stress conditions such as temperature and atmosphere modification to maximize storage potential of fresh crops. As highlighted by Kays, from a postharvest physiologist's position, stress is an external factor that will result in undesirable changes only if the plant or plant part is exposed to it for a sufficient duration or sufficient intensity. The postharvest period, in this context, can be seen as a time of stress management (Watkins 2003).

Therefore, it could be concluded that, preharvest factors greatly influence both the condition of the crop at harvest and the crop's storage and nutritive potential. The postharvest quality of fresh horticultural commodities markedly depends upon the quality attained at the time of harvest. Many preharvest factors are known to affect storage quality, including: genotype and cultivar selection; stage of maturity when harvested; climatic conditions such as temperature, light intensity, and rainfall amounts; soil texture and fertility; fertilizer type and application rates; disease and insect pressure; and growth regulator and pesticide application.

4 Processing of Fruits and Vegetables for Reducing Postharvest Losses

Despite decades of educational efforts, the most common causes of postharvest losses in developing countries continue to be rough handling and inadequate cooling and temperature maintenance. The lack of sorting to eliminate defects before storage and the use of inadequate packaging materials further add to the problem. In general, minimizing rough handling, sorting to remove damaged and diseased produce and effective temperature management will help considerably toward maintaining a quality product and reducing storage losses. Storage life will be enhanced if the temperature during the postharvest period is kept as close to the optimum as feasible for a given commodity (Tables 10 and 11; Kitinoja and Kader 2002).

Time and money are required to cultivate food products, and unless the farmer is providing food only for his own household, he automatically becomes part of the market economy: he must sell his produce, he must recover his costs, and he must make a profit. Estimates of the post-harvest losses of food grains in the developing world from mishandling, spoilage and pest infestation are put at 25 %; 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 mostly quickly perishable,

Table 10 Classification of some fruits and vegetables according to principal causes of postharvest losses and poor quality and in order of importance

Group	Examples	Principal causes of postharvest losses and poor quality (in order of importance)
Root vegetables	Carrots	Mechanical injuries
	Beets	Improper curing
	Onions	Sprouting and rooting
	Garlic	Water loss (shriveling)
	Potato	Decay
	Sweet Potato	Chilling injury (subtropical and tropical root crops)
Leafy vegetables	Lettuce	Water loss (wilting)
	Chard	Loss of green color (yellowing)
	Spinach	Mechanical injuries
	Cabbage	Relatively high respiration rates
	Green onions	Decay
Flower vegetables	Artichokes	Mechanical injuries
	Broccoli	Yellowing and other discolorations
	Cauliflower	Abscission of florets
		Decay
Immature-fruit vegetables	Cucumbers	Over-maturity at harvest
	Squash	Water loss (shriveling)
	Eggplant	Bruising and other mechanical injuries
	Peppers	Chilling injury
	Okra	Decay
	Snap beans	
Mature-fruit vegetables and fruits	Tomato	Bruising
	Melons	Over-ripeness and excessive softening at harvest
	Citrus	Water loss
	Bananas	Chilling injury (chilling sensitive fruits)
	Mangoes	Compositional changes
	Apples	Decay
	Grapes	
	Stone fruits	

Adapted from Kitinoja and Kader (2002)

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 sometimes as high as so 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 (Simson and Straus 2010).

The fruit and vegetable sector has grown substantially both in volume and in variety of outputs traded globally. Rising incomes, falling transportation costs, improved

Table 11 Classification of fresh horticultural crops according to their relative perishability and potential storage life in air at near optimum temperature and relative humidity

Relative perishability	Potential storage life (weeks)	Commodities
Very high	<2	Apricot, blackberry, blueberry, cherry, fig, raspberry, strawberry; asparagus, bean sprouts, broccoli, cauliflower, green onion, leaf lettuce, mushroom, muskmelon, pea, spinach, sweet corn, tomato (ripe); most cut flowers and foliage; minimally processed fruits and vegetables.
High	2–4	Avocado, banana, grape (without SO2 treatment), guava, loquat, mandarin, mango, melons (honeydew, crenshaw, Persian), nectarine, papaya, peach, plum; artichoke, green beans, Brussels sprouts, cabbage, celery, eggplant, head lettuce, okra, pepper, summer squash, tomato (partially ripe).
Moderate	4–8	Apple and pear (some cultivars), grape (SO2-treated), orange, grapefruit, lime, kiwifruit, persimmon, pomegranate; table beet, carrot, radish, potato (immature).
Low	8–16	Apple and pear (some cultivars), lemon; potato (mature), dry onion, garlic, pumpkin, winter squash, sweet potato, taro, yam; bulbs and other propagules of ornamental plants.
Very low	>16	Tree nuts, dried fruits and vegetables.

Adapted from Kader (1993)

technologies and evolving international agreements, have all contributed to this level of growth. This increased level of fruit and vegetable production has, unfortunately, not been matched by developments in supply chain management, or by vertical integration of production with processing in many developing countries. Processing activities are of critical importance to expansion and diversification within the fruit and vegetable sector in that they increase market opportunities for fresh fruits and vegetables and add value while minimizing postharvest losses. Furthermore, processing improves the viability, profitability and sustainability of fruit and vegetable production systems by increasing farm incomes, and generating rural employment and foreign exchange. Traditional processing technologies such as thermal processing (bottling and canning), freezing, dehydration (salting, brining and candying) drying, and fermentation are widely applied in the processing of fruits and vegetables at various levels (artisanal, intermediate and high) and scales (cottage, small, medium and large). Tropical juices and fruit pulps, canned pineapples, tomato paste and canned and dried mushrooms are examples of fruit and vegetable products produced using traditional processing technologies and which are increasingly entering in international trade (Rolle 2006).

Dried and canned mushrooms produced in China, currently account for 52 % of world trade in processed mushrooms, while canned pineapples produced in Thailand accounts for approximately 45 % of that product in world trade. Minimal processing technologies, specialized packaging and natural preservation systems are increasingly being applied in the preservation of fruits and vegetables for both developed and developing country markets, in response to growing consumer demand for convenience and for "fresh-like" fruits of high quality which are nutritious, flavorful and stable. These processing technologies focus on adding value with comparatively little product transformation while increasing product diversity. While minimal and traditional processing technologies present considerable opportunities for innovation and vertical diversification in the fruit and vegetable sector, relatively few small and medium enterprises (SMEs) are able to tap into and benefit from these opportunities. Many SMEs lack the capacity to operate competitively in the current globalized market environment owing to problems of scale, the poor quality of input supplies, poor access to technology, limited technical expertise and research capacity, low production efficiency, high marketing cost, lack of knowledge and consequently inability to comply with international standards for processed products. Traditional processing technologies, applied in the conservation of horticultural produce employ a gradient of technologies, ranging from artisanal to intermediate to high technologies. Major categories of processed products produced with the use of these technologies include fruit preserves, fruit and vegetable juices, fermented products (wines and vinegars), candied products and frozen and dried products (Rolle 2006).

The keeping and the preparation of fresh produce after harvest affects its nutritional value in several ways, for example:

- Dry-matter content is reduced with time as the continuation of living processes within the produce uses up stored food reserves.
- Vitamin C content decreases with time after harvest, and little may remain after 2 or 3 days (Table 12).
- Cooking partially destroys vitamins C and B_1. Raw fruit and vegetables are particularly valuable provided they are grown and handled hygienically.
- Peeling may cause significant loss of food value, especially in potatoes, where the protein content is just beneath the skin.
- Water used in cooking vegetables or fruit contains the dissolved minerals and trace elements of the food and should not be thrown out but used in soups or in preparing other foods (Simson and Straus 2010).

Table 12 Vitamins supplied by fruit, vegetables and root crops

Vitamin	Name	Source
A	Retinol	From carotene in dark green leaves, tomatoes, carrots, papayas
B_1	Thiamine	Pulses, green vegetables, fruit (cereal grains have B. in germ and outer-seed coat)
B_2	Riboflavin	Green leafy vegetables and pulses
B_6	Pyridoxin	Bananas, peanuts
PP	Niacin (nicotinic acid)	Pulses, peanuts
–	Folic acid	Dark green leaves, broccoli, spinach, beets, cabbage, lettuce, avocados
C	Ascorbic acid	Dark green leaves, spinach, cauliflower, sweet pepper, citrus, guava, mango, papaya

Adapted from Simson and Straus (2010)

Therefore, it could be concluded that, the lack of sorting to eliminate defects before storage and the use of inadequate packaging materials further add to the problem. In general, minimizing rough handling, sorting to remove damaged and diseased produce and effective temperature management will help considerably toward maintaining a quality product and reducing storage losses. Storage life will be enhanced if the temperature during the postharvest period is kept as close to the optimum as feasible for a given commodity. The fruit and vegetable sector has grown substantially both in volume and in variety of outputs traded globally. Processing activities are of critical importance to expansion and diversification within the fruit and vegetable sector in that they increase market opportunities for fresh fruits and vegetables and add value while minimizing postharvest losses.

5 Development of Storage Science

Some of the first experiments in which ripening of fruit was intentionally altered by changing the storage atmosphere were carried out in France by Jacques Berard around 1820. He demonstrated that fruit use O_2 and generate CO_2 while in storage, and if totally deprived of O_2, they did not ripen. Berard found that apples, apricots, peaches, pears, and prunes could be stored in an altered gas environment, and following their removal to ambient air and room temperature, were edible for extended periods. Refrigeration has had a significant effect on the development of fruit and vegetable storage technology. The rationale for quickly lowering the temperature of harvested crops is essentially the same today as it was in antiquity: refrigeration greatly reduces food spoilage and waste. Although ice and snow have been used since the Roman era to preserve perishable foodstuffs, it was not until the 1800s that natural ice from the colder climes of the northern hemisphere was commonly used to refrigerate foods worldwide. It could be summarized development of storage science as follows (Table 13; De Long and Prange 2003; Fig. 8):

Date	Events
In the 1860s	**Benjamin Nyce**, an Ohio commercial storage operator, found that when he limited O_2 surrounding his fruit in an ice-refrigerated store, the produce was greatly improved. Nyce did not license the patent rights for his storage system despite strong commercial interest to implement the method, thus, it was not widely adopted. Ironically, Nyce's work resulted in a de facto prototype for modern controlled atmosphere (CA) storage, which, unfortunately, was not further developed for another 60 years.

(continued)

Date	Events
In the early 1890s	The **San Jose Fruit Packing Company** experimented with augmented CO_2 levels as a preserver of fruit. In a railroad car experiment, a load of grapes, peaches, pears, persimmons, and quinces stored in elevated CO_2 and without refrigeration were in good condition following 11 days of travel, and held up well in the retail chain. In other early experiments with storage gas modification, elevated CO_2 was found to be helpful, but could not completely compensate for lack of refrigeration. Temperature control was/is fundamental for preservation of fruit and vegetable quality, with modification of the O_2 and CO_2 atmosphere being an important but secondary quality preservation method.
In the 1920s	**Kidd and West**, working at the Low Temperature Research Station in Cambridge, UK, conducted a number of experiments to determine the optimal atmospheric gas concentrations, i.e., lower O_2 and higher CO_2, for storing apples. It was known at that time that respiration fueled the generation of metabolic heat, which was deleterious to fruit quality in long-term storage. Therefore, one of the goals of their research was to reduce the rate of storage respiration. Their studies led to assigning the term “climacteric” to indicate the burst of postharvest respiration in apples, which is now known to occur in many important fruit crops. In subsequent years, Kidd and West also became increasingly aware of the role of ethylene in the climacteric rise in apples.
In the 1930s	Following the seminal work of Kidd and West, CA storage became more common globally, although the UK was the first country to initially adopt commercial CA storage practices. This was soon followed by South Africa, the United States, Canada, Australia, New Zealand, Denmark, and the Netherlands. Today, CA storage is standard practice worldwide and is largely responsible for the high marketplace quality attained for many CA responsive fruits and vegetables. Interestingly, the challenge facing each major geographical region that adopted CA technology in the 1920s and 1930s is the same today: finding the optimal combination of temperature, O_2, and CO_2 for each species, cultivar, and even strain that leads to the highest quality retention for the longest duration. This goal is always tempered by the technology available and the economic viability of sustaining the storage environment for the desired length of time.

Therefore, it could be concluded that, some of the first experiments in which ripening of fruit was intentionally altered by changing the storage atmosphere were carried out in France by Jacques Berard around 1820. He demonstrated that fruit use O_2 and generate CO_2 while in storage, and if totally deprived of O_2, they did not ripen. Refrigeration has had a significant effect on the development of fruit and vegetable storage technology. The rationale for quickly lowering the temperature of harvested crops is essentially the same today as it was in antiquity: refrigeration greatly reduces food spoilage and waste.

Table 13 Recommended temperature and relative humidity for fruits and vegetables and the approximate storage life under these conditions

Crop	Temperature (°C)	Relative humidity (%)	Storage life (days)
Apple	−1 to 4	90–95	30–180
Apricot	−0.5 to 0	90–95	7–21
Artichoke	0	95–100	14–21
Asparagus	0–2	95–100	14–21
Avocado	3–13	85–90	14–56
Banana – Plantain	13–15	90–95	7–28
Barbados cherry	0	85–90	49–56
Basil	7–10	85–90	7
Bean (dry)	4–10	40–50	180–300
Beet (bunched)	0	98–100	10–14
Beet (topped)	0	98–100	120–180
Black berry	−0.5 to 0	90–95	2–3
Blue berries	−0.5 to 0	90–95	14
Broad beans	0–2	90–98	7–14
Broccoli	0	95–100	14–21
Cabbage	0	98–100	150–180
Cactus leaves	2–4	90–95	14–21
Cantaloupe (half slip)	2–5	95	15
Cantaloupe (full slip)	0–2	95	5–14
Carrot (bunched)	0	95–100	14
Carrot (topped)	0	98–100	210–270
Cassava	0–5	85–96	30–60
Cauliflower	0	95–98	21–28
Celery	0	98–100	30–90
Cherries	−1 to 0.5	90–95	14–21
Chicory	0	95–100	14–21
Chinese cabbage	0	95–100	60–90
Chives	0	95–100	14–21
Coconut	0–1.5	80–85	30–60
Cucumber	10–13	95	10–14
Dates	−18 to 0	75	180–360
Eggplant	8–12	90–95	7
Fig	−0.5 to 0	85–90	7–10
Garlic	0	65–70	180–210
Ginger	13	65	180
Grape	−0.5 to 0	90–95	14–56
Grapefruit	10–15	85–90	42–56
Green onions	0	95–100	21–28
Guava	5–10	90	14–21
Horse radish	−1 to 0	98–100	300–360
Jerusalem artichoke	−0.5 to 0	90–95	120–150
Kiwi fruit	−0.5 to 0	90–95	90–150
Kohlrabi	0	98–100	60–90
Kumquat	4	90–95	14–28

(continued)

Table 13 (continued)

Crop	Temperature (°C)	Relative humidity (%)	Storage life (days)
Leek	0	95–100	60–90
Lemon	10–13	85–90	30–180
Lettuce	0–2	98–100	14–21
Lima bean	3–5	95	5–7
Lime	9–10	85–90	42–56
Mandarin	4–7	90–95	14–28
Mango	13	90–95	14–21
Melon (Others)	7–10	90–95	12–21
Mushrooms	0–1.5	95	5–7
Nectarine	–0.5 to 0	90–95	14–28
Okra	7–10	90–95	7–10
Onions (dry)	0	65–70	30–240
Olives, fresh	5–10	85–90	28–42
Orange	0–9	85–90	56–84
Papaya	7–13	85–90	7–21
Parsley	0	95–100	30–60
Parsnip	0	95–100	120–180
Peach	–0.5 to 0	90–95	14–28
Pear	−1.5 to 0.5	90–95	60–210
Peas	0	95–98	7–14
Cucumber	5–10	95	28
Pepper (bell)	7–13	90–95	14–21
Persimmon	−1	90	90–120
Pineapple	7–13	85–90	14–28
Plum	–0.5 to 0	90–95	14–35
Pomegranate	5	90–95	60–90
Potato (early)	7–16	90–95	10–14
Potato (late)	4.5–13	90–95	150–300
Pumpkins	10–15	50–70	60–160
Quince	–0.5 to 0	90	60–90
Radish	0	95	21
Raspberries	–0.5 to 0	90	2
Snap beans	4–7	95	7–10
Snow peas	0–1	90–95	7–14
Spinach	0	95–100	10–14
Sprouts	0	95–100	7
Strawberry	0–0.5	90–95	5–7
Sweet corn	0–1.5	95–98	5–8
Sweet potato	13–15	85–90	120–210
Summer squash	5–10	95	7–14
Taro	7–10	85–90	120–150
Tomato (red)	8–10	90–95	8–10
Turnip	0	90–95	120
Water melon	10–15	90	14–21
Yam	16	70–80	60–210

Adapted from FAO (2004)

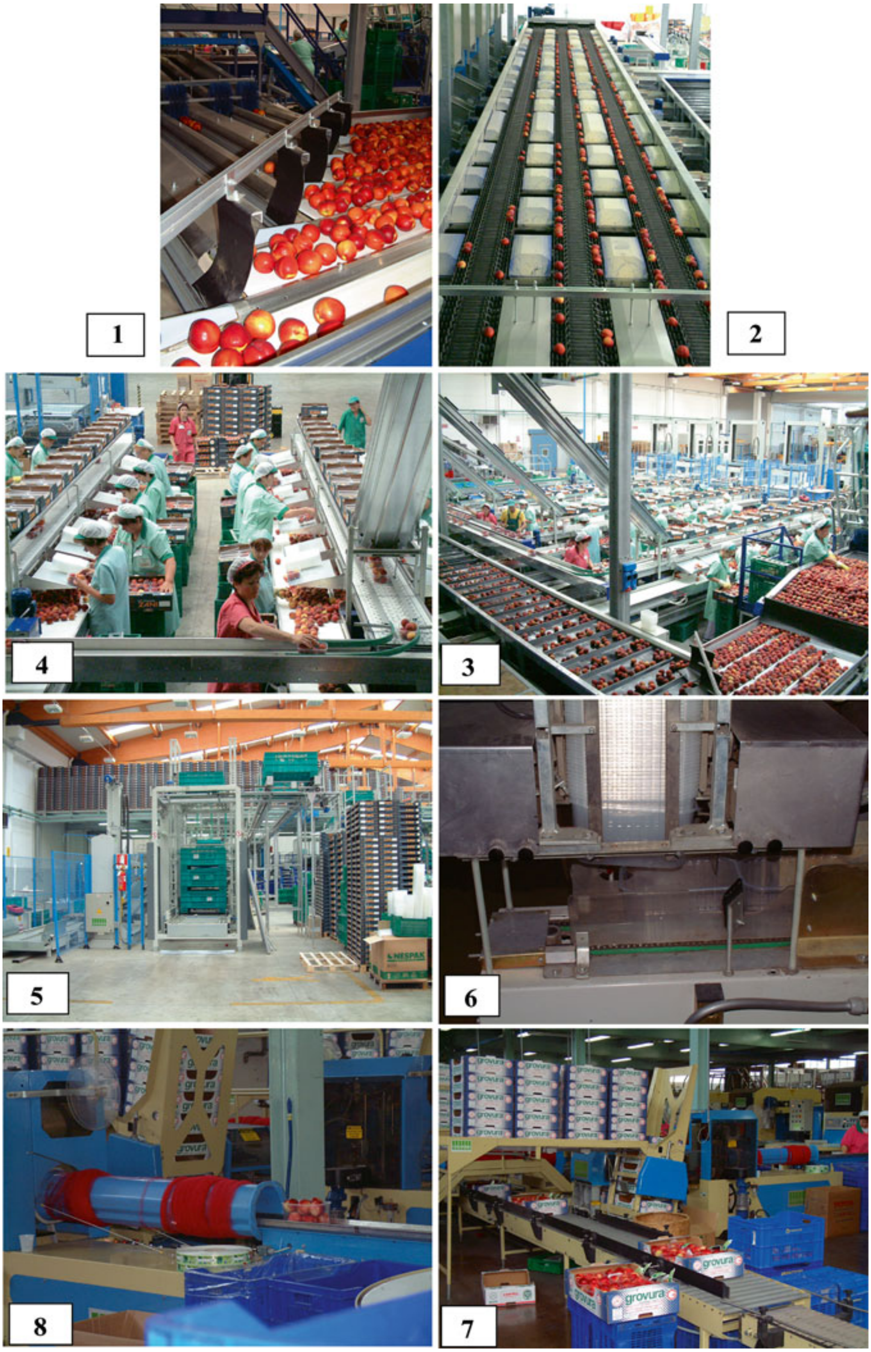

Fig. 8 Processing of fruits for reducing postharvest losses in Cesena in Italy. Sorting to eliminate defects before storage (Photos 1, 2, 3 and 4) and the use of inadequate packaging materials further add to the problem. Storage life will be enhanced if the temperature during the postharvest period is kept as close to the optimum as feasible for a given commodity (Photos 5, 6, 7 and 8) (Photo by M. Fári)

6 Postharvest Biology and Technology: A Perspective

Fruits and vegetables as well as their processed products have become mainstream human dietary choices in recent days, primarily because of several epidemiological studies showing various health benefits associated with the consumption of fruits, vegetables, and their processed products. Fruits and vegetables share several common structural and nutritional properties and also characteristic differences due to differences in their biochemical composition. Fruits, in general, are attractive organs for vectors involved in seed dispersal, and thus have evolved features such as enhanced color, attractive flavor, and taste. Consequently, the developmental and biochemical processes within a fruit are programmed to achieve this goal. The term *vegetables* is more or less arbitrary, comprising products such as leaves, petioles, stems, roots, tubers, and fruits of cucurbits e.g., gourds, melons, squash, and pumpkin and solanaceae members e.g., tomato and eggplant. Morphologically, fruits develop from the ovary, the seed-bearing structure in plants. The developmental processes in fruits are influenced by fertilization, and the hormonal changes induced in the ovary leads to gene expression and biochemical changes resulting in the characteristic fruit that may vary in ontogeny, form, structure, and quality. Fruits originate from different parts of the ovary. Pome fruits such as apple and pear develop from the thalamus of the flower. In drupe fruits such as cherries, peaches, plums, and apricots, the ovary wall (mesocarp) develops into the fruit enclosing a single seed. Berry fruits, such as tomato and grape, possess the seeds embedded in a jellylike pectinaceous matrix, with the ovary wall developing into the flesh of the fruit. Citrus fruits belong to the class known as hesperidium, where the ovary wall develops as a protective structure surrounding the juice-filled locules that are the edible part of the fruit. In strawberry, the seeds are located outside the fruit, and it is the receptacle of the ovary (central portion) that develops into the edible part. Most vegetables are leaves, petioles, or stems containing chlorophyll, or roots, tubers, or fruits that predominantly contain storage components such as starch. Examples include potato and eggplant (Solanaceae), gourds (Cucurbitaceae), several types of yams (Dioscoreaceae and Araceae), vegetables of leaf and flower origin (cabbage, broccoli, cauliflower—Cruciferae), and unripe fruits of leguminous plants such as peas and beans (Leguminosae). The nutritional and food qualities of fruits and vegetables arise as a result of the accumulation of components derived from the intricate biochemical pathways (Paliyath and Murr 2008a).

Postharvest practices for the preservation of fruits, vegetables, and flowers are perhaps one of the oldest in human history. With the understanding of the molecular processes that occur during plant senescence, this discipline has developed unique features of its own. Traditionally, postharvest science is considered as an applied science focusing on the physiological aspects of enhancement of shelf life and preservation of quality of horticultural produce. However, in the past two decades, biochemical and molecular biological aspects have been extensively used for analyzing postharvest issues. Postharvest issues are common around the world. The extent of the loss of horticultural produce after harvest can vary in different countries. In those parts of the world where the methods of agricultural production and storage employ advanced technology, postharvest losses may be minimal, and most of it occurs during the transit of produce from the production site to the destination along the consumer chain. The losses can range from 10 to 20 % by volume. In tropics where the production practices are basic and based on day-to-day demand, the postharvest losses can be as high as 50 % or over. It is surprising and a bit disturbing to see that fruits are considered as luxury items in some parts of the world. In an era where we consider the consumption of fruits and vegetable as a means of health promotion, postharvest science gets a new meaning (Paliyath et al. 2008).

Fruit ripening is characterized by several marked physiological and biochemical changes resulting in the coordinated development of complex characteristics. Following pollination and fertilization, the fruit develops in size leading to the ripening process, which results in the development of ideal organoleptic characters such as taste, color, and aroma that are important quality-determining features. Fruits that are used as vegetables are harvested early prior to their ripening. The physiological process of ripening occurs rapidly when the fruit is mature, and beyond a certain stage, harvested fruits undergo rapid deterioration in quality. Ideally, fruits are harvested at an optimal physiological stage or maturity characteristic to the type of fruit, after which appropriate storage procedures can be adopted for preserving the shelf life and quality of the fruits. Fruits do not ripen fully showing the appropriate quality characteristics if picked at a young stage before the attainment of physiological maturity. Citrus fruits are allowed to fully ripen before they are harvested. Avocado fruits do not ripen if left on the tree and start ripening only after harvest. Irrespective of the nature of the produce whether it is fruits, vegetables, or flowers, various technologies such as cold storage, controlled atmosphere storage, and inhibition of hormone and enzyme action are adopted to slow down the metabolic processes to provide an optimal quality produce for marketing and consumption.

Advances in the biochemistry and molecular biology of the fruit ripening process have enabled the development of biotechnological strategies for the preservation of postharvest shelf life and quality of fruits, vegetables, and flowers. Several metabolic changes are initiated after the harvest of fruits and vegetables. In the case of vegetables, harvesting induces stress responses through reduced availability of water and nutrients, wounding, and exposure to shelf life enhancing storage methods such as cooling. In most cases, these changes help the produce to enhance the shelf life. In the case of fruits, an increase in the biosynthesis of the gaseous hormone ethylene serves as the physiological signal for the initiation of the ripening process. In general, all plant tissues produce a low, basal, level of ethylene. During the ripening process, some fruits evolve large amounts of ethylene, sometimes referred to as an autocatalytic increase in ethylene production, which occurs in conjunction with an increase in respiration referred to as the respiratory climacteric. Fruits are generally classified into climacteric or nonclimacteric types on the basis of the pattern of ethylene production and responsiveness to externally added ethylene. The climacteric fruits characteristically show a marked enhancement in ethylene production and respiration, as noticeable by the evolution of carbon dioxide. By contrast, the nonclimacteric fruits emit a considerably reduced level of ethylene. In climacteric fruits such as apple, pear, banana, tomato, and avocado, ethylene evolution can reach 30–500 ppm/(kg h) (parts per million, μL L^{-1}), whereas in nonclimacteric fruits such as orange, lemon, strawberry, and pineapple, ethylene levels usually range from 0.1 to 0.5 ppm/(kg h) during ripening. Climacteric fruits respond to external ethylene treatment by an early induction of the respiratory climacteric and accelerated ripening in a concentration-dependent manner. Nonclimacteric fruits, on the other hand, show increased respiration in response to increased levels of ethylene concentration without showing acceleration in the time required for ripening. Vegetables produce very low amounts of ethylene most of them with less than 0.1 μL/(kg h), with slightly higher levels as in cassava (1.7 μL/(kg h)), breadfruit (1.2 μL/(kg h)), and cucumber (0.6 μL/(kg h)) when measured at 20–25 °C. After the initiation of ripening or harvest, several biochemical changes occur in fruits and vegetables. As some of these changes such as the development of color, flavor, and sweet taste are desirable for fruits, any sort of quality changes are ideally not desired in vegetables. Thus, strategies for the preservation of shelf life and quality in fruits and vegetables could be entirely different. It is important to know the biochemical differences between fruits and vegetables and several biochemical pathways that operate in these tissues to develop ideal conditions of storage for the preservation of shelf life and quality (Paliyath and Murr 2008a).

Therefore, it could be concluded that, fruits and vegetables share several common structural and nutritional properties and also characteristic differences due to differences in their biochemical composition. Postharvest practices for the preservation of fruits, vegetables, and flowers are perhaps one of the oldest in human history. With the understanding of the molecular processes that occur during plant senescence, this discipline has developed unique features of its own.

7 Biochemical Parameters of Horticultural Crops Quality

There are two major aspects that define the quality of a produce: the first being the inherent biochemical characteristics that provide the color, flavor, texture, and taste to the produce and the second being the consumer perception. The application of postharvest technologies tends to maximize these quality characteristics, though application of some technologies may not provide the optimal quality produce for the consumer. During ripening, activation of several metabolic pathways occurs, often leading to ideal changes in the biochemical composition of fruits. The stage of development in a fruit determines its biochemical composition and the quality-defining parameters. Color is perhaps the first parameter that attracts a consumer to a produce. Hence, fruits that show enhanced yellow-orange-red hue are preferred by the consumer. The composition of anthocyanins and carotenoids in a fruit will determine its color quality characteristics. Consumers also associate the depth of color with the taste, though this is influenced by practical experiences. In general, fruits that are bright red are also sweet. Some of the exceptions include sour cherries and red currants. Brightly colored fruits also tend to possess the ideal texture. Flavor is also an important component to the quality perception, and the degree of ripeness determines the level and types of flavor components such as esters and terpenoids emitted from the fruit. Aroma is derived from several types of compounds that include monoterpenes (as in lime, orange), ester volatiles (ethyl, methyl butyrate in apple, isoamyl acetate in banana), simple organic acids such as citric and malic acids (citrus fruits, apple), and small-chain aldehydes such as hexenal and hexanal (cucumber) (Paliyath and Murr 2008a).

In fruits such as mango, pineapple, strawberry, and grape, the ripening process is associated with the conversion of stored organic acids and starch into sugars, and enhanced evolution of flavor components. The presence of off-flavors resulting from the presence of certain aldehydes e.g., acetaldehyde may negatively impact quality perception, whereas other aldehydes such as hexanal tend to enhance the green flavor and consumer preference of vegetables. The evolution of sulfur volatiles in crucifer vegetables e.g., broccoli and cabbage and *Allium* vegetables (onion, garlic) is characteristic to their quality. In a similar way, the evolution of essential oils in Lamiaceae members (mint, oregano, rosemary, etc.) also attracts consumers. Fruits and vegetables contain a large percentage of water, which can often exceed 95 % by fresh weight. Texture and the degree of softness are determined by the amount of water contained in the produce and the ability to retain that water during postharvest storage. The degradation of cell wall components and the cell membrane negatively affects the rigidity of the tissue in fruits providing the softness that consumers prefer (degradation of stored starch in banana), though excessive degradation of these components reduces the shelf life of the fruits drastically (Paliyath and Murr 2008a).

Most vegetables are preserved to maximize the high textural integrity, and loss of water from vegetables negatively affects their quality. The consumers are increasingly becoming aware of the disease-preventive and health-restoring roles of fruits and vegetables, because of which they are classified as functional foods. Many quality-determining components are also regarded as important functional food ingredients (nutraceuticals) that include soluble and insoluble fibers, color components such as anthocyanins and carotenoids, several polyphenolic components, and sulfur-containing components in crucifer and *Allium* vegetables. Fruits in general contain large amounts of fibrous materials such as cellulose and pectin. The breakdown of these large polymers into smaller water-soluble components during ripening leads to fruit softening as observed during the breakdown of pectin in tomato and cellulose in avocado. Secondary plant metabolites are major ingredients of fruits. Anthocyanins are the major color components in grapes, blueberries, apples, and plums; carotenoids, specifically lycopene and carotene, are the major color components in tomatoes, and these components provide the health benefits to consumers through their antioxidant property and ability to influence metabolic processes within the human body. Fruits are also rich in vitamin C, which is a strong antioxidant. Vegetables such as asparagus are rich in glutathione, another component in the antioxidant defense system (Paliyath and Murr 2008a).

Lipid content is quite low in fruits; however, fruits such as avocado and olives store large amounts of triacylglycerols (oils). The amounts of proteins are usually low in most fruits. It is interesting to note that a majority of edible fruits and vegetables tend to group in certain families. For instance, some of the edible fruit-dominated families include Annonaceae, Rosaceace, Myrtaceae, Rutaceae, Oxalidaceae, and Anacardiaceae among the dicots. Bananas and plantains are the major monocot fruits (Musaceae). The major dicot vegetable families include Fabaceae, Solanaceae, Cruciferae, Cucurbitaceae, Compositae, Umbelliferae, Lamiaceae, and Dioscoreaceae. Monocot families such as the Liliaceae and Araceae are rich in vegetables. The following are some specific characteristics of fruits and vegetables (Paliyath and Murr 2008a).

Several metabolic changes are initiated after the harvest of fruits and vegetables. In the case of vegetables, harvesting induces stress responses through reduced availability of water and nutrients, wounding and exposure to shelf life, enhancing storage methods such as cooling. In most cases, these changes help the produce to enhance the shelf life. In the case of fruits, an increase in the biosynthesis of the gaseous hormone ethylene serves as the physiological signal for the initiation of the ripening process. In general, all plant tissues produce a low, basal, level of ethylene. During the ripening process, some fruits evolve large amounts of ethylene, sometimes referred to as an autocatalytic increase in ethylene production, which occurs in conjunction with an increase in respiration referred to as the respiratory climacteric. Fruits are generally classified into climacteric or nonclimacteric types on the basis of the pattern of ethylene production and responsiveness to externally added ethylene (Paliyath and Murr 2008b).

The climacteric fruits characteristically show a marked enhancement in ethylene production and respiration, as noticeable by the evolution of carbon dioxide. By contrast, the nonclimacteric fruits emit a considerably reduced level of ethylene. In climacteric fruits such as apple, pear, banana, tomato, and avocado, ethylene evolution can reach 30–500 ppm/(kg h) (parts per million, microliter/L), whereas in nonclimacteric fruits such as orange, lemon, strawberry, and pineapple, ethylene levels usually range from 0.1 to 0.5 ppm/(kg h) during ripening. Climacteric fruits respond to external ethylene treatment by an early induction of the respiratory climacteric and accelerated ripening in a concentration-dependent manner. Nonclimacteric fruits, on the other hand, show increased respiration in response to increased levels of ethylene concentration without showing acceleration in the time required for ripening. Vegetables produce very low amounts of ethylene most of them with less than 0.1 μL/(kg h), with slightly higher levels as in cassava (1.7 μL/kg h), breadfruit (1.2 μL/kg h), and cucumber (0.6 μL/kg h) when measured at 20–25 °C. After the initiation of ripening or harvest, several biochemical changes occur in fruits and vegetables. As some of these changes such as the development of color, flavor, and sweet taste are desirable for fruits—any sort of quality changes are ideally not desired in vegetables. Thus, strategies for the preservation of shelf life and quality in fruits and vegetables could be entirely different. It is important to know the biochemical differences between fruits and vegetables and several biochemical pathways that operate in these tissues to develop ideal conditions of storage for the preservation of shelf life and quality (Paliyath and Murr 2008b).

Fruits contain a large percentage of water that can often exceed 95 % by fresh weight. During ripening, activation of several metabolic pathways often leads to drastic changes in the biochemical composition of fruits. Fruits such as banana store starch during development and hydrolyze the starch to sugars during ripening that also results in fruit softening. Most fruits are capable of photosynthesis, store starch, and convert them to sugars during ripening. Fruits such as apple, tomato, and grape have a high percentage of organic acids, which decreases during ripening. Fruits contain large amounts of fibrous materials such as cellulose and pectin. The degradation of these polymers into smaller water-soluble units during ripening leads to fruit softening as exemplified by the breakdown of pectin in tomato and cellulose in avocado. Secondary plant products are major compositional ingredients in fruits. Anthocyanins are the major color components in grapes, blueberries, apples, and plums; carotenoids, specifically lycopene and carotene, are the major components that impart color in tomatoes. Aroma is derived from several types of compounds that include monoterpenes (as in lime, orange), ester volatiles (ethyl, methyl butyrate in apple, isoamyl acetate in banana), simple organic acids such as citric and malic acids (citrus fruits, apple), and small chain aldehydes such as hexenal and hexanal (cucumber). Fruits are also rich in vitamin C. Lipid content is quite low in fruits, the exceptions being avocado and olives, in which triacylglycerols (oils) form the major storage components. The amounts of proteins are usually low in most fruits (Paliyath and Murr 2008b).

Fruit ripening is a dynamic transitional period during which many easily perceived changes, such as alterations in pigmentation, firmness, sweetness, and acidity take place. These changes make fruit desirable for human consumption and capable of seed dispersal by birds, animals, and environments. Fruit firmness is associated with several attributes including crispness, mealiness, grittiness, chewiness, succulence and juiciness, fibrousness, toughness, and oiliness. Additionally, development of various organoleptic components such as sweetness, sourness, astringency, bitterness, and production of volatile compounds leading to characteristic aroma is connected with fruit textural changes. Although most of these changes impart desirable traits to various fruits and vegetables, some of the fruit softening associated changes make them unacceptable for marketing. These include development of off-flavors and off-odors with excessive softening of tissues. Textural softening can also increase susceptibility to phytopathogens due to their proneness to solute leakage that provide rich media for their growth, and resulting in severe losses during postharvest storage and marketing (Prasanna et al. 2007).

Large economic losses results from inability to retard ripening-associated excessive softening of fruits between harvest and marketing. These losses occur due to culling of perishable commodities at field and packinghouses, grading, storage, transit, retail, and consumer. In developing countries, theses losses can range between 10 and 100 %, especially due to phytopathogen-related tissue rotting of certain commodities. The economic consequences of postharvest fruit softening have led to considerable interests of geneticists, physiologists, biochemists, and in recent year's molecular biologists to understand the molecular basis of fruit softening. The last 40 years have seen a significant increase in our understanding of biochemical changes associated to fruit textural modifications. Emerging recombinant DNA technologies including reverse genetics have begun to provide some answers. In this section, it could be described the relationship of cell wall chemistry and various families of cell wall–modifying enzymes to the developmentally regulated softening of fruit during ripening. Also discussed are various postharvest factors affecting structural deterioration of fruit crops and potential of chemical or genetic means to reduce crop losses (Negi and Handa 2008).

Therefore, it could be concluded that, most vegetables are preserved to maximize the high textural integrity, and loss of water from vegetables negatively affects their quality. There are two major aspects that define the quality of a produce: the first being the inherent biochemical characteristics that provide the color, flavor, texture, and taste to the produce and the second being the consumer perception.

8 Postharvest Factors Affecting Structural Deterioration

The major postharvest problem with storage of fruits and vegetables is the excessive softening. Ripening of many fruits is mainly orchestrated by biosynthesis of ethylene that triggers a serial biochemical and physiological process inducing the softening in texture. The most important factors affecting structural deterioration of fruits and vegetables can be summarized as follows:

I. **Processing**
At low extraction percentages (up to 33 %), pectic polysaccharides and hemicellulosic xyloglucans were the main type of polymers affected, suggesting the modification of the cell wall matrix, although without breakage of the walls. At higher extraction rates (up to 64 %), a major disruption of the cell wall occurred as indicated by the losses of all major types of cell wall polysaccharides, including cellulose. At higher extraction rates, fatty acid chains are able to exit the cells either through unbroken walls, or the modification of the pectin-hemicellulose network might have increased the porosity of the wall. Due to high pressure, a progressive breakage of the cell walls was observed, which allows the free transfer of the fatty acid chains from inside the cells (Negi and Handa 2008).

II. **Heat**
Postharvest heat treatments lead to an alteration of gene expression, and fruit ripening can sometimes be either delayed or disrupted. Cell wall–degrading enzymes and ethylene production are frequently the most disrupted, and their appearance is delayed following heating. Fruit sensitivity to heat treatments is modified by preharvest weather conditions, cultivar, rate of heating, and subsequent storage conditions. Prestorage heat treatment appears to be a promising method of postharvest control of decay. Heat treatments against pathogens may be applied to fresh harvested commodities by hot water dips, by vapor heat, by hot dry air, or by a very short hot water rinse and brushing. Prestorage heat treatment could delay the ripening of "Gala" and "Golden Delicious" apples and

maintain storage quality (Shao et al. 2007). Heating "Golden Delicious" apples for 4 days at 38 °C reduced decay and maintained fruit firmness during 6 months of storage at 0 °C. Cooking resulted in an increase in the water-soluble pectins and a decrease in the pectins associated with cellulose. The total cell wall polysaccharide and galactose content of the squash cultivars remained unchanged for up to 2 months of storage and decreased later (Negi and Handa 2008).

III. Physiological disorders

Water soaking developed during the late stages of fruit ripening. The major changes were observed in a protein implicated in calcium signaling processes. While the amount of total calmodulin, the ubiquitous calcium-binding protein, was not modified, a particular calmodulin-binding protein (CaM-BP) was absent in water-soaked but not in sound mature tissues. This CaM-BP may be a marker or a determinant of this physiological disorder. Gel breakdown in inner mesocarp tissue of plums was associated with high viscosities of water-soluble pectin with low levels of extractable juice. In outer mesocarp tissue where extractable juice levels were higher, over-ripeness developed. Cell walls of inner tissue were thicker and had a better developed middle lamella than outer tissue. Inner mesocarp tissue was composed of larger cells than outer tissue (Negi and Handa 2008).

IV. Chilling and freezing injury

Insoluble pectin levels declined during ripening and cold storage of plum fruit with a concomitant increase in soluble pectin levels. Neither harvest maturity nor storage time had a significant effect on the concentration of calcium pectate, and this pectic fraction did not appear to influence development of gel breakdown (GB). Water-soluble pectin and availability of cell fluids indicated a high gel potential in plums. Significant levels of GB developed only in plums harvested at postoptimum maturity. In GB fruit, higher sugar levels and loss of cell membrane integrity probably enhanced formation of pectin sugar gels as cell fluids bind with pectins in cell walls. The initial response to low temperature is considered to involve physical factors such as membrane alteration and protein/enzyme diffusion, but physiological changes that lead to losses of structural integrity and overall fruit quality also occur. During softening, dissolution of the ordered arrangement of cell wall and middle lamella polysaccharides occur. As the fruit ripens, a substantial portion of its cell wall pectins are converted to a water-soluble form affecting the texture. The major changes involved in softening and chilling injury in peaches are the catabolism of cell walls and the development of an intercellular matrix containing pectins. Gel-like structure formation in the cell wall due to the deesterification of pectins without depolymerization leads to the development of woolliness in peach (Lurie et al. 2003). Ruoyi et al. (2005) showed that combination of chitosan coating, calcium chloride, and intermittent warming partially inhibited PG activity, slowed down the increase in soluble pectinefic substances. Addition of calcium chloride and intermittent warming could keep the intactness of cell wall and reduce fruit sensitivity to injury in peach. Endo-PG, PE, and endoglucanase (EGase) activities of delayed-storage nectarines fruit were same as the control fruit at the beginning of storage, although exo-PG was higher. Endo-PG activity was lower in control than delayed-storage fruit at the end of storage, while PE activity was higher, and exo-PG and EGase activities were similar. Prevention of chilling injury by delayed storage (DS) appears to be due to the ability of the fruit to continue progressive and slow cell wall degradation in storage, which allows normal ripening to proceed when the fruits are rewarmed (Negi and Handa 2008).

V. Modified atmosphere

Fruit softening is associated with the disassembly of primary cell wall and middle lamella structure. The changes in cell wall structure and composition result from the composite action of hydrolytic enzymes produced by fruits, which include PG, PE, PL, β-GAL, and cellulases. High-oxygen atmosphere retards the decrease in firmness in grapes (Deng et al. 2005), sweet cherries (Tian et al. 2004), fresh-cut carrots (Amanatidou et al. 2000), and strawberries (Wszelaki and Mitcham 2000). Deng et al. (2005) observed that decrease in firmness of grapes under different oxygen storage was accompanied by a dramatic decrease in hemicellulose and moderate decrease in cellulose and total pectins, which indicates that the softening in grapes is due to increased depolymerization and degradation of cell wall polysaccharides. At higher oxygen storage, grapes maintained firmness, which coincided with higher retention of cell wall polysaccharides. The lower levels of water-soluble pectins in high-oxygen atmosphere were correlated with delayed softening, and the activities of PG, PE, β-GAL increased to lower extent than air storage, which indicates that higher oxygen might have inhibited relative enzyme activities, reducing the degradation and depolymerization of pectin substances. Cellulase activity in grapes increased slightly over time, and its activity was slightly lower in high oxygen compare to air (Deng et al. 2005). In controlled atmosphere (CA)-stored apples, ripening-related softening was inhibited after an initial loss of firmness. However, softening resumed after transfer of apples to normal atmosphere storage at 8 °C (Negi and Handa 2008).

VI. Pathogen attack

In apple and tomato fruits, *Penicillium expansum* infection caused reduction in the molecular mass of hemicelluloses, particularly in the xyloglucan. Xyloglucan endotransglucosylase/hydrolase (XTH)-specific activity decreased drastically during the infection process in both fruits. XTH reduction during the infection might be related with the fungus attack mechanism. Decrease in activity and the consequent lower xyloglucan endotransglucosylation, together with the increase in endoglucanases, would permit fungal access to the cellulose-xyloglucan network, increase the efficiency of cellulose hydrolysis, and thus facilitate the progress of the fungal infection. Hemicellulose degradation is important in the breakdown of plant cell walls, causing cell wall loosening, increasing the porosity of the wall, and allowing the colonization of plant tissue (Miedes and Lorences 2004).

VII. Irradiation

The biological effect of gamma rays is based on the interaction with atoms or molecules in the cell, particularly water, to produce free radicals, which can damage different important compounds of plant cell. The UV-B/C photons have enough energy to destroy chemical bounds, causing a photochemical reaction. Gamma rays accelerate the softening of fruits, causing the breakdown of middle lamella in cell wall. They also influence the plastid development and function, such as starch–sugar interconversion. The penetration of UVB light into the cell is limited, while gamma rays penetrate through the cells. For this reason, UV-B light has a strong effect on surface or near-to-surface area in plant cells. Plant pigments, such as carotenoids and flavonoids, save plant cells against UV-B and gamma irradiation (Kovacs and Keresztes 2002). UV light has been used as a postharvest treatment to enhance shelf life of various fruits and vegetables. The beneficial doses of UV-C are reported to induce the accumulation of phytoalexins and activate genes, encoding pathogenesis-related proteins. Prestorage exposure of peaches with UV-C irradiation significantly reduced chilling injury. A higher accumulation of spermidine and spermine was found in peaches after UV exposure, and it is postulated that these higher levels of polyamines apparently are a response to the UV-C irradiation and might be beneficial in increasing the resistance of fruit tissue to deterioration and chilling injury (Negi and Handa 2008).

Therefore, it could be concluded that, the major postharvest problem with storage of fruits and vegetables is the excessive softening. Ripening of many fruits is mainly orchestrated by biosynthesis of ethylene that triggers a serial biochemical and physiological process inducing the softening in texture. The most important factors affecting structural deterioration of fruits and vegetables are processing, heating, physiological disorders, chilling and freezing injury, pathogen attack, modified atmosphere and irradiation.

9 Challenges in Handling Fresh Fruits and Vegetables

Postharvest losses of fruits and vegetables can be very large depending upon the product and the specific conditions. However, the same factors causing losses will also affect the health-related characteristics of the fruits and vegetables that are eaten. Sometimes there is a direct relation between the appearance of a product and its health-related properties. However, it is probable that in most cases it is impossible to judge the nutritional quality and phytochemical contents by means of our senses. Fresh fruits and vegetables are detached, but still living, plant parts that continue to respire and have metabolic activities. They also to a large extent maintain protective systems such as physical barriers and physiological defence mechanisms. This is in contrast to minimally processed fruits and vegetables that have a larger surface area with tissues that are cut through and open to microbial attack, drying and dust. If not eaten, the products have a limited lifetime before they die and decay. Eating quality is at its highest level at harvest, or it will reach a peak during the postharvest period if the particular product has a clear maturation process and has been picked unripe. Both the keeping quality, or keep ability (the ability to maintain an acceptable quality over time) and the eating quality (the quality at a certain time), as well as the rate of quality change, are determined by a series of biotic and abiotic factors pre- and postharvest. The postharvest factors include species, variety, microbial load, presence of pests, temperature, radiation exposure, atmosphere composition including relative humidity and possible mechanical stress or damage. These factors in turn affect the rate of the deterioration processes, which are essentially physiological (senescence) and microbial (Bengtsson and Matforsk 2008).

The postharvest lifetime is not just the time spent in various stores, but also includes time for washing, sorting, packaging, transport and distribution. In fact, many exported perishable plant products spend most of their time in transport, wholesale and retail. Therefore, different fresh fruits and vegetables can have postharvest lifetimes ranging from less than a week to up to a year. The shelf-life is determined as the time between a starting point (for instance harvest or beginning of distribution) and an end point when the product has reached a minimum acceptable quality for human consumption under defined storage and distribution conditions. Intake of fresh fruits and vegetables of sufficient quantity and quality is not only necessary for maintaining good human health, but is also very important for sensory satisfaction. On the other hand, sufficient sensory quality is a prerequisite for achieving a high enough intake. The present review will focus on the quality of whole fruits and vegetables related to human health as affected by storage and treatments that are common in the commercial distribution of fruit and vegetables, but will also include, when available, data on sensory quality. Health-related quality is defined as the quality related to both nutrients and other constituents that have an effect on human health, preferentially those with a health-promoting effect. The literature on storage effects on fruits and vegetables is very large and the amount of research focusing on health-related quality has increased dramatically since the 1980s (Bengtsson and Matforsk 2008).

In general, at optimum cold storage conditions vitamin C content is decreasing, whereas most phenolics, carotenoids, glucosinolates and dietary fibres are relatively stable (Table 14). Deviations from optimum conditions may indeed affect the contents of health-related constituents. Suboptimum temperature and humidity usually give rise to enhanced rates of breakdown due to increased metabolism leading to faster maturation and senescence. Some constituents, such as phenolics, can increase their content under dehydration (without change in total amount) or when exposed to visible or UV radiation (with increased total amount). Except for vitamin C and phenolics, storage effects on nutrients and health-promoting phytochemicals have not been investigated to any great extent.

Most of the postharvest research on health-related quality has focused on the effects of various factors on constituent levels. In the future, emphasis will be more on the mechanisms behind the observed changes in order to get a deeper understanding of the phenomena. This means that genomics, proteomics and metabolomics

Table 14 General effects of storage on contents of health-related constituents of fruits and vegetables

	Optimal temp.	Suboptimal temp.	Incident light	Reduced O_2	Elevated CO_2	Elevated O_2	Dehydration
Vitamin C	Decrease	Decrease	Decrease	Slower decrease			Decrease
Phenolics, fruits and vegetables	Stable	Decrease	Increase	Stable or increase	Stable or increase		Variable
Phenolics, berries	Increase	Increase	Variable	Stable or decrease	Stable or decrease	Increase	Increase
Carotenoids, fruits	Variable	Variable					
Carotenoids, carrots	Stable		Stable				Decrease
Carotenoids, green vegetables	Variable	Variable	Variable				
Glucosinolates	Stable or decrease	Decrease		Variable	Increase		Decrease
Dietary fibre	Stable	Variable					

Adapted from Bengtsson and Matforsk (2008) should be used in studies of the regulation of the metabolic pathways of constituents. This does not necessarily indicate that the goal is to create a basis for production of transgenic fruits and vegetables, which can be useful in research, but which give rise to a great deal of resistance from large consumer groups. The knowledge can be used in conventional breeding programs to select lines for optimum sensory and health-related quality and for achieving optimized pre- and postharvest treatment for each individual plant product (Bengtsson and Matforsk 2008).

Therefore, it could be concluded that, postharvest losses of fruits and vegetables can be very large depending upon the product and the specific conditions. However, the same factors causing losses will also affect the health-related characteristics of the fruits and vegetables that are eaten. The postharvest lifetime is not just the time spent in various stores, but also includes time for washing, sorting, packaging, transport and distribution. Many exported perishable plant products spend most of their time in transport, wholesale and retail. Therefore, different fresh fruits and vegetables can have postharvest lifetimes ranging from less than a week to up to a year.

10 Postharvest Handling Under Extreme Weather Conditions

The modern era of informatics and high-technology communications has allowed many growers, shippers and retailers to learn and implement practices and technologies that have had success elsewhere in the world. There have been many examples where technological protocols were "*copied on the local level*," and the results were similar to those previously experienced. However, we are also continually reminded that what is done at one site cannot be transmitted directly to another, even when similar cultivars are grown. The interesting point, and the good news for those working to improve postharvest quality of produce, is that a successful plan of production and handling to maintain quality may only need simple adjustments to produce good standards in other operations. It is paramount to stress the importance of environmental factors occurring during the hours before and immediately after harvest, particularly when those factors involve extreme conditions prevalent in places such as low deserts and rainy tropics. Research has shown the direct effects of environmental conditions during the hours before harvest on postharvest quality (Fonseca 2006).

A single stress event can produce major physical changes in the physiology and anatomy of the plant upon recovery. For example, trichomes were formed in feverfew plants after recovering from a wilting event (Fonseca et al. 2005), and grafted watermelon produced adventitious roots and aerenchyma to adapt to a single flooding (Yetisir et al. 2006). Environmental factors encountered during handling of produce that can affect final quality include extremely low or high temperatures, rain and extremely low relative humidity (RH). It is possible that in the future, with more urban areas coexisting with production fields and orchards, other factors may become more important, such as environments with high emissions of CO_2, as well as atmosphere with low pressure and high ethylene content (Fonseca 2009). It could be followed the postharvest handling under extreme weather conditions as follow:

I. ***Postharvest handling in the tropics***

Postharvest losses encountered in tropical areas with a high incidence of rainfall are likely the highest in the world. Losses in developing countries along the tropical belt are estimated to be about 50 % (FAO 1989). Interestingly, there was no significant relationship between solar radiation and mean temperature. It could be concluded that fruit that were exposed on the day of harvest, or during the 3 days before harvest, to minimum temperatures higher than 22.4 °C showed improved tolerance to quarantine heat treatments. This induced-tolerance to postharvest heat treatments has been associated with heat shock proteins. High RH and temperatures around 30 °C can enhance wound healing of citrus fruits (Kinay et al. 2005). This is a major reason for the recommendation that degreening treatments occur in high RH and controlled temperatures. This beneficial effect is associated with a fast wound healing rate, triggered by the formation of lignin and the induction of antifungal compounds, such as scoparone and scopoletin. The proliferation and/or penetration in the fruit by pathogens, such as *Penicillium digitatum*, *P. italicum* and *Geotrichum candidum* is reduced when curing is induced under high RH and temperatures around 30 °C (Plaza et al. 2003). High temperatures during postharvest storage are commonly associated with high transpiration rates and subsequent degradation of quality traits. However, in the case of herbs such as marjoram even temperatures as high as 30 °C do not affect oil accumulation, but rather can stimulate synthesis. Temperatures and light intensity in tropical areas fluctuate less than in hot, dry or temperate climates. Although it is not completely clear how the low daily temperature fluctuation impacts the postharvest quality of fruit, some studies suggest that shelf life of vegetative tissue may be significantly impacted by the time of day of harvest (Fonseca 2009).

In tropical countries, the production of shoot tip cutting for export to temperate countries is a major industry. It has been found that late harvests e.g. after 4 pm improve storage quality and subsequent rooting response, an effect that was attributed to higher endogenous carbohydrate status (Rapaka et al. 2007). On the other hand, vegetative tissue is particularly sensitive to storage temperature during the hours after harvest, which may be dependent on the time of the day or harvest if cooling facilities are not available. Chlorophyll degradation significantly increases in leafy vegetables, such as Valeriana lettuce (Ferrante and Maggiore 2007) and fresh-cut rocket and spinach (Ferrante et al. 2004), when storage temperature increases by only 6 °C. Diurnal changes in metabolism may explain the prolonged shelf life obtained with harvest during the late hours of the day. Xyloglucan endotransglusylase-hydrolase, a cell wall modifying protein, is more active during the late hours of the day, suggesting a role in preventing cell degradation during postharvest. Moreover, leaf–water relations are also known to fluctuate during the day. For example, stomata opening occurs in response to light and temperature which affects CO_2 uptake productivity and assimilation of carbon productions. The "turgor" hypothesis is another factor that can partially explain the importance of weather conditions at harvest. It is agreed by many that prolonged shelf life may augment with increased turgor, which may be also improved with postharvest calcium treatments (Rico et al. 2007).

Rapid cooling at sunset inhibits the export of sugars from the leaves to the fruit, which results in increased osmotic and turgor pressure. Extreme rainy conditions can have direct implications on plant disease and food safety. Clinical pathogens that invade fruit and vegetables generally benefit from high RH encountered in the field and during postharvest storage, with some exceptions, such as the case of *E. coli* O157:H7 (Stine et al. 2005). Another exception is the Hepatitis A virus, which is quite stable in the environment, with the longest survival having been reported at low RH. In contrast, high RH has been found to afford Salmonella longer survival on the surface of tomato plants (Rathinasabapathi 2004). Because of the potential risk with added moisture in tissue at harvest (Fonseca 2006), it is probably wise to schedule harvest for periods when the rain stops and there has been enough time to dry water from the surface of the tissue to be harvested. Additional concerns exist in the tropics when extreme weather conditions prevail, because efficiency of postharvest operations may decline faster as field workers in charge of harvest, selection or classification may be more at risk of dehydration (Nag et al. 2007).

II. ***Postharvest handling in the desert***

The deserts, which may be present from sea level to 3,500 m, are places where large quantities of produce are grown (Houston 2006). In all deserts, to different degrees, cold nights and/or high temperatures during the day prevail during certain times of the year. Such conditions may be even more extreme than usual during times which may coincide with the harvest of edible tissue. Production of plant crops in the desert often includes high sunlight intensity, low relative humidity (RH) and high temperatures, depending on the season in which the crop is planted, which in some cases is inadequate to support even microbial life (McKay et al. 2003). Low RH is of particular concern, since fresh-harvested commodities tend to lose weight rapidly at low RH. Changes in water status alter the general conditions of the product with economic losses being due to both decreased quality and product weight. Most fruits and vegetables become unmarketable with a loss of 5–10 % of their initial weight. The rate of water loss and subsequent weight are clearly dependent on factors such as temperature and RH. The water status of the product at harvest, in addition to extreme environmental conditions during postharvest, may affect quality (Fonseca 2009).

Water activity, the differential between vapor pressure of water in food and vapor pressure in pure water, affects the water loss rate of a fresh commodity. Higher water activity (or less negative water potential) implies higher amount of water that could be easily released to the environment in the form of water vapor pressure. Lettuce with extremely high water activity showed lower shelf life, particularly if accompanied by extremely low RH during postharvest handling (Fonseca 2006). The loss of membrane integrity associated with desiccations, leads to loss of cellular compartmentation, which consequently allows polyphenol oxidase and polyphenol substrates to mix in the damaged cells, resulting in tissue browning. Color retention and quality of beans was found to be higher when the product had lower moisture content. While initial moisture content of near 14 % yielded shelf life of lower than 10 days, initial moisture content of near 11 % produced shelf life of above 100 days (Karathanos et al. 2006).

Herbs in particular suffer great weight loss when conditions at harvest include high temperatures. The rate of transpiration in herbs is commonly 100 % higher than that of vegetable species showing intensive respiration. Freshly harvested Saint-John's Wort shows a Q10 of 2.60 over the range 10–20 °C and 1.93 over the range 20–30 °C (Bottcher et al. 2003). However, for herbs that are dried, the rapid loss of water did not commonly affect the key active compounds (Fonseca et al. 2006). The quality of asparagus spears clearly varies depending on the weather conditions prevalent during the growth cycle (Bhowmik et al. 2002), but postharvest conditions may be more critical in influencing final quality. In a greenhouse study, the variability in the monthly temperature during the growth of asparagus did not consistently show an affect on breaking force, regardless of the subsequent storage conditions. However, a clear relationship was found between the temperature during postharvest storage and the breaking force of shear asparagus spears (Bhowmik et al. 2003).

High temperatures at harvest time can affect level of decay during postharvest as observed in France with Star Ruby grapefruit (Pailly et al. 2004). Clearly, crops such as broccoli, beans, peas and asparagus harvested at an over-mature stage will be prone to excessive accumulation of fiber content, a factor that will become more pronounced if weather conditions include high temperatures. Extremely high temperatures at harvest impact hormonal levels in the marketed, edible portion of agricultural perishables. Abscisic acid (ABA) is known to fluctuate during the day. ABA seems to peak before the maximum light intensity or prior to the onset of the maximum daily temperatures (Fonseca et al. 2005). This could be explained by the high rate of photo-oxidation during late morning and afternoon hours, which exceeds that rate of synthesis of ABA (Simkin et al. 2003). It has been shown that higher ABA levels at harvest result in a shorter vase-life of cut roses. The accumulation of ABA is tissue specific, as light sources have caused changes in ABA levels in rose petals, but not in their leaves (Fonseca 2009).

Desert crops are particularly exposed to conditions that pose at least a mild stress. Water stress is one of the most common stresses that plants encounter due to excess of transpiration during certain periods of plant growth. Changes in water availability during late phases of growth are so dramatic that a single stress event can trigger alterations to the anatomy of a leaf. Formation of trichomes was observed in feverfew upon recovery from a single wilting event (Fonseca et al. 2005). If plants are under severe stress at the moment of harvest, due to extreme weather conditions or abuse through agricultural practices, the result on the postharvest quality is commonly negative. For example, French fries made from potatoes grown under stress have shown undesirable texture. However, in some cases, mild water stress at harvest under desert conditions has resulted in clear benefits for the quality of intact and fresh-cut produce such as lettuce (Fonseca 2006).

When a mist was induced during the hours prior to harvest, the low temperature breakdown of kiwifruit occurring during postharvest storage was reduced or eliminated, depending on the maturity of the fruit at harvest. This was associated with higher accumulation of chilling time before harvest (Sfakiotakis et al. 2005). Some studies suggest that the time of the year at which harvest takes place may be critical in the shelf life of crops. Increase of dry and fatty matter, polyphenol and antioxidant composition in cauliflower was obtained in a year when plants were subjected to stress conditions (Lo Scalzo et al. 2007). In the same study it was suggested that early harvested product was more suitable for storage due to the higher ration of unsaturated as compared to saturated fatty acids. Regardless of the location of apple fruits in the canopy of the tree, time of the year affected the concentration of ripening associated pigments. For example, in a November harvest content of lutein in apples was lower and violaxanthin higher than in a June harvest (Solovchenko et al. 2006).

Another factor to consider when handling fruits and vegetables in desert conditions is light. Light intensity during postharvest storage is an issue that has been overlooked for a long time; however, it could have a significant effect on final quality, particularly when excess intensity reaches the product. It is now known that harvested product may respond to light in ways that can dramatically affect quality. Solanine content in potatoes exposed to sunlight was increased as high as eight times that found in potatoes stored in the dark. The concentration of solanine obtained with varieties grown in the desert and exposed to sunlight during harvest reached levels of 150 and 90 mg/100 g, far above what has been found in other markets. Levels of solanine above 20 mg/100 g of fresh tuber are considered toxic. Using materials to prevent light from reaching the product has been suggested. The use of reflective tarpaulins for covering bins containing recently-harvested cherries reduced the incidence of pitting in cherries by nearly 20 %. In the case of cherries, water loss is faster in the stems, and the use of reflective tarpaulins for only four hours also increased moisture levels by over 15 % (Schick and Toivonen 2002).

III. Effect of drastic changes occurring during postharvest handling

Adaptation of fruit and vegetables to extreme postharvest handling conditions may be affected by previous conditions occurring during preharvest or during early stages of handling and storage. The effect can be beneficial or detrimental. Cucumbers developed no symptoms of chilling injury during postharvest handling when preharvest temperatures in the greenhouse were 5 °C higher, i.e. fruits grown at 27 °C developed symptoms, cucumber grown at 32 °C did not show any symptoms. Temperature sensitivity and ethylene production was reduced in the fruits from plants grown at the higher temperature. However, weight loss was significantly higher in cucumber grown at the higher temperature. In another study with cucumber, fruit stored at 36–40 °C for 24 h before refrigeration storage significantly reduced subsequent respiration and the appearance of pitting (Fonseca 2009).

Factors occurring before harvest affect the quality of produce. In particular, postharvest responses of fruit and vegetables to chilling stress are often greatly influenced by preharvest field temperature. These factors may be associated with biological agents, physiological mechanisms, mechanical damage, cultural practices, genetic variation or environmental factors. In fact, there are few postharvest disorders of fruits and vegetables that are not affected by preharvest factors. Treatment with air temperature at 36–40 °C reduced chilling injury of Hass avocado fruit. For high quality avocado the temperature and exposure to sunlight during preharvest is critical. For example, skin tissue on the side of the fruit exposed to the sun exhibited less chill injury and heat damage. Tolerance of postharvest heat treatment is affected by air temperatures experienced in the field 3 days before harvest. Retention of nutrients may also be improved with higher preharvest temperature.

Fruit grown in the shady inner areas of the canopy have a greater incidence of chilling injury than fruit grown in the outer areas of the canopy. This finding indicates more efficient preharvest practices to allow higher light penetration would be beneficial. Practices which could be used may include pruning and leaf removal (Forlani et al. 2002). Extremely high temperatures in destination markets during summer months may require adjustments in earlier steps in the postharvest chain to reduce deterioration of quality. Produce in transoceanic shipments often suffers from abrupt changes in temperature when arriving at the destination port. Cassava root for export markets stored at 15 °C kept for a longer time than that stored at 10 °C when the product was shipped during the summer season to the end market (Fonseca and Saborío 2001). This was likely due to a higher transpiration rate and subsequent condensation of water between the skin and paraffin wax in the product stored at lower temperatures, due to a drastic change with the extremely high ambient temperature on the patios of the brokers. The opposite was observed during the winter season. That is, low storage temperatures during transportation extended the shelf life of cassava root (Fonseca 2009).

The activities of antioxidant enzymes, such as catalase and ascorbate peroxidase, decreased under high RH (85–90 %), whereas superoxide reductase increased and glutathione reductase decreased at low RH (55–60 %), an indication of their possible role in lowering rind staining in Navelina oranges (Sala and Lafuente 2004). These observations have important implications for the desert citrus industry, as harvesting may be done during extremely low RH, and the fruit may dehydrate before being stored in coolers, which are expected to be at high RH. Extreme weather conditions trigger responses in plants that involve activity of enzymes and growth regulators. The protective function of enzymes against different stress conditions in plants has been reported (Rubio et al.

Table 15 Fruits and vegetables rich in the different groups of antioxidants

Ascorbic acid	Vitamin E	Carotenoids	Phenolics
Strawberry	Almond	Pineapple	Blueberry
Pepper	Corn	Plum	Plum
Kiwifruit	Broccoli	Peach	Raspberry
Orange	Spinach	Pepper	Strawberry
Pepper	Peanut	Mango	Apple
Broccoli	Avocado	Melon	Blackberry
Guava		Tomato	
Persimmon		Carrot	

Adapted from Vicente et al. (2009)

2002). The involvement of plant hormones in the stress-induced antioxidant system has also been reported (Table 15; Arora et al. 2002).

The time of the day of harvest may critically affect the shelf life of horticultural crops. The shelf life of sweet basil increased by almost 100 % when harvest was done late in the day compared to harvest done in the morning, a reaction that could be due partially to changes in carbohydrate composition. Accumulation of carbohydrates increases during the day as a product of photosynthesis. Increased accumulation of carbohydrates reduces CO_2 sensitivity in lettuce and chilling sensitivity in tomato seedlings. Improved shelf life due to increased extensible cell walls has been correlated to harvesting product during the late hours of the day. The same was found with leafy greens subjected to mechanical stress (Clarkson et al. 2003). Time of day of harvest has also been shown to affect the shelf life of commodities, particularly leafy greens. Shelf life was extended by as much as 6 days in arugula and 2 days in lollo rosso and red chard, when the harvest was done at the end of the day (Clarkson et al. 2005). The time of the month or the time of the day of harvest has been associated with produce quality (Fonseca 2009).

Even when following strict quality control programs, harvested products could still be subjected to stress-producing conditions during handling and storage. The stress can be a result of a single environmental factor, or the outcome of a combination of factors encountered throughout different stages of production and handling. Extreme weather conditions may cause severe losses to growers, especially when operations fail to manage quality in other steps, or when conditions are part of multiple failures. If environmental conditions at harvest and during postharvest handling differ, the result may range from severely-affected products to maximum-quality products. Although it is not possible to eliminate losses due to environmental conditions, the extent of these losses can be reduced through a better understanding of the nature of the problem and by being proactive with implementing potential solutions. Extreme weather conditions differ in nature and affect different commodities in various ways. However, based on studies described in this chapter, some general conclusions can be drawn (Table 16). Research has shown that single

Table 16 Extreme environmental conditions encountered during different postharvest steps and factors that influence the impact of those conditions on quality of the final product

Extreme environmental conditions	Potential negative impact	Factor that may enhance or reduce the impact
Extremely low relative humidity at harvest	Rapid water loss and early development of dehydration symptoms.	Water activity/potential at harvest affects the weight loss. Product with extremely high water activity shows symptoms of dehydration more quickly.
Extremely high relative humidity at harvest	Excess moisture on surface of product can result eventually in large loss of water and oxidation of tissue. It can also produce condensation of water vapor in packages, affording ideal conditions for proliferation of pathogens.	Depending on the product, a time dedicated to release excess water may aid in prolonging shelf life.
Extremely low temperature at harvest/early day hours	Freezing damage. Early day hours produce higher incidence of leaf abscission of vegetative cuttings.	Materials used to cover crops or equipment to elevate the air temperature are currently used commercially.
Extremely high temperature/sunlight intensity at harvest/late day hours	Accumulation of undesired compounds in certain crops such as potatoes. Reduced production of ethylene and subsequent loss of leaves during transition.	Use of transpirants and rapid movement of product from field to refrigeration conditions is used to ameliorate potential negative effects.
Extremely low temperature during postharvest handling	Chilling injury	Temperature during the growth of the plant can affect sensitivity. Plants grown in higher temperatures better tolerate the chilling temperatures. Postharvest heat treatments may aid in reducing sensitivity as well.
Extremely high temperature during postharvest handling	Occurrence of proliferation of plant pathogens. Microorganisms in general will be afforded better conditions to grow.	Risk is reduced if a good preharvest program to control diseases is in place, and relative humidity previous to harvest was not high.
Extremely high temperature at destination port	Abrupt raise in respiration and transpiration of the product. Condensation of water in product packages and spaces between wax and cuticles. Potential for microorganisms' growth.	Higher temperature and transpiration during transition may reduce problems by reducing condensation. Packages, films and coatings with sufficient permeability for gas diffusion is an option.

Adapted from Fonseca (2009)

extreme weather factors can be highly detrimental to the final quality of the marketed commodity. It is also clear that the potential negative impact may be ameliorated when the product is previously exposed to determined conditions (Fonseca 2009).

Therefore, it could be concluded that, environmental factors encountered during handling of fruits and vegetables produce that can affect final quality include extremely low or high temperatures, rain and extremely low relative humidity. High temperatures during postharvest storage are commonly associated with high transpiration rates and subsequent degradation of quality traits. However, in the case of herbs such as marjoram even temperatures as high as 30 °C do not affect oil accumulation, but rather can stimulate synthesis.

11 Postharvest Stress Treatments in Fruits and Vegetables

Fruits and vegetables are an important source of carbohydrates, proteins, organic acids, vitamins, and minerals for human nutrition. When humans use plants or plant parts, whether for food or for aesthetic purposes, there is always a postharvest component that leads to loss (Fallik 2004). Their losses in quantity and quality affect horticultural crops between harvest and consumption. Thus, to reduce the losses, producers and handlers must understand the biological and environmental factors involved in deterioration (Kader 1992). Fresh fruits and vegetables are living tissues subject to continuous changes after harvest. While some changes are desirable, most are not (Kader 1992). Their commodities are perishable products with active metabolism and subject to extensive postharvest losses through microbial decay, physical injury, and senescence during the postharvest period. However, postharvest changes in horticultural crops cannot be stopped, but they can be slowed within certain limits (Kader 1992). The maintenance or improvement of the postharvest life of fresh fruits and vegetables is becoming increasingly important (Imahori 2012).

Fresh fruits and vegetables are living tissues subject to continuous changes after harvest. While some changes are desirable, most are not. Their commodities are perishable products with active metabolism during the postharvest period. Proper postharvest handling plays an important role in increasing food availability. Postharvest stress treatments have been shown to be generally effective in controlling both insect and fungal pests, reducing physiological disorder or decay, delaying ripening and senescence, and maintaining storage quality in fruits and vegetables. In addition, a moderate stress not only induces the resistance to this kind of severe stress, but also can improve tolerance to other stresses. Postharvest stress treatments can, therefore, be very important to improving shelf life and quality retention during postharvest handling of fruits and vegetables.

Harvested fruits and vegetables can be potentially exposed to numerous abiotic stresses during production, handling, storage and distribution (Hodges 2003). Some of these stresses can be minor in nature, resulting in no quality loss or, in some cases, in quality improvement (Hodges et al. 2005) during distribution. However, when the abiotic stress is moderate or severe, quality losses almost always are incurred at market. As a consequence it is important to understand the nature and sources for abiotic stresses that affect fruits and vegetables. In addition, with improved understanding, options for better management or resistance become available (Toivonen 2005). One of the challenges facing fruit and vegetable production globally is that regional climate regimes are becoming more unpredictable from year to year. Hence understanding of effects of field abiotic stresses e.g. drought, extreme temperatures, light and salinity on postharvest stress susceptibility will become more important since postharvest stresses limit the storage and shelf life potential of fruits and vegetables (Toivonen 2005). It is the intent of this section to first describe the nature of pre- and post-harvest abiotic stress events, delve into their importance for product quality and marketing and then explore the technologies available to begin managing the sensitivity of fruits and vegetables to stresses they encounter in the handling and distribution chain.

I. Effect of preharvest stresses on fruits and vegetables

Abiotic stresses occurring during production can either be the primary cause (direct) for disorders that exhibit themselves during postharvest handling and storage practices or they can influence the susceptibility of a fruit or vegetable to postharvest conditions that cause abiotic stresses resulting in disorders (indirect). It is important to characterize the relationship between preharvest abiotic stresses occurring during production and postharvest abiotic stresses that the fruit or vegetable is exposed after harvest and during storage and distribution, since the solution to these different problems will be best resolved by focusing on preharvest or postharvest abiotic stress amelioration, respectively. Moderate levels of preharvest stress can potentially work towards enhancing stress resistance of a fruit or vegetable through up-regulating genes and pathways which renders the tissues cross-tolerant to many stresses which may occur subsequently in postharvest handling, storage and distribution (Toivonen and Hodges 2011).

1. Drought

The occurrence of drought conditions during production of fruit and vegetable crops is becoming more frequent with climate change patterns. While much work has been devoted to understanding of drought effects on production and productivity of these crops (Whitmore 2000), there is limited published literature on the effects of preharvest water stress on responses to postharvest stresses and hence on subsequent quality and shelf life. However, the existing literature provides some insight which may lead to better understanding and perhaps also encourage future research. Water stress during the production phase of some fruits and vegetables may affect their physiology and morphology in such a manner as to influence susceptibility to weight loss in storage. There have been both positive effects reported for field water deficits (stress) in tree fruits and root vegetables. In the case of peaches, it has been shown that lower levels of irrigation results in higher density of fruit surface trichomes and consequent lower weight losses in storage. In addition, some studies have shown that deficit irrigation of apples and pears could reduce water loss of these fruit in subsequent storage (Lopez et al. 2011) and this was attributed to reduction in skin permeance of the deficit irrigated fruit. Presumably, fruit grown under moderate water stresses imposed by deficit irrigation practices adapt by developing a less water permeable cuticle. In terms of understanding that water deficits can have negative effects on postharvest stress susceptibility, irrigation of apples has been shown to enhance apple size which was associated with lower to water losses during storage. This observation highlights a main concern about using deficit irrigation, which is the reduced size of fruit from such treatments (Lopez et al. 2011). Size of fruit is important, since larger fruit have lower surface area to volume ratios, which confers lower relative water loss. Another negative affect associated with water deficits is the case of root vegetables, such as carrot, where preharvest water stress (watering to 25–75 % of soil water field capacity) can weaken the cells, resulting in higher membrane leakage (i.e. cell damage) and consequently greater weight loss in storage (Toivonen and Hodges 2011).

2. **Plant nutrition**

There is limited literature regarding the effects of crop nutrition on the susceptibility of fruits and vegetables to postharvest abiotic stress. There is one review dealing with the effect of preharvest nutrition on postharvest physiology and disorders of fruits and vegetables (Sams and Conway 2003), however most of the reviewed literature touches on nutrition effects on postharvest biotic stress effects (i.e. disease resistance). Calcium nutrition during production has been well documented in regard to postharvest disorders of many fruits and some vegetables (Sams and Conway 2003). Calcium is also been suggested as a putative signaling molecule involved in the development of cross tolerance to abiotic stresses. Therefore, the role of preharvest calcium nutrition is postharvest stress resistance may be complex, and dependent on whether the fruit or vegetable is also exposed to environmental abiotic stresses. Potassium nutrition has been shown to have a few important effects on postharvest abiotic stress susceptibility of vegetables. In carrots, deficiency in potassium is associated with greater weight loss (desiccation stress) in storage. At levels below 1 mM potassium in the soil medium, weight loss was directly associated with increased membrane leakage (i.e. damaged cells) in the carrot tissues. Above 1 mM potassium, there were no significant differences in weight loss under standardized storage conditions. Improved potassium nutrition has also been shown to reduce susceptibility of potatoes to internal bruising in response to mechanical stresses imposed during postharvest handling. Relatively high preharvest nitrogen is often associated with poor postharvest quality of many fruits and vegetables (Sams and Conway 2003). In regards to affecting susceptibility to postharvest stress, applying higher than recommended levels of preharvest nitrogen for a specific crop have been linked to storage discoloration susceptibility in both cabbage and potato. In the case of cabbage, it appears that excessive nitrogen fertilization leads to high accumulations of zinc and aluminum and nitrate induced manganese deficiency. High nitrogen applications in the field resulted in increased incidence and severity of black midrib in cold storage, particularly for the susceptible cultivar, 'Safe keeper'. In the case of potatoes, black spot susceptibility (a consequence of bruising) is influenced by nitrogen fertilization, particularly the balance of nitrogen applied in relation to levels of potassium applied. In contrast nitrogen deficiency or lower than recommended nitrogen application rates will most often results in increased vitamin C content in many fruits and vegetables. Vitamin C content has been tightly linked with storage life potential (Hodges et al. 2001), which is likely a consequence of the importance of this antioxidant nutrient in forestalling oxidative injury that leads to quality losses in storage (Toivonen and Hodges 2011).

3. **Temperature extremes**
   Susceptibility to high heat injury inducing or low chill injury inducing, temperatures is known to be reduced by prior exposure of the sensitive fruit or vegetable to low ambient temperatures. However, if the preharvest temperature leads to chilling induced injury in the field, then susceptibility to postharvest chilling injury can be increased. Therefore, the level of the preharvest temperature extreme will be a determinant as to if the exposure will have positive or negative effects on postharvest stress sensitivity. Extreme high temperatures can occur in the field and apple fruit exposed to direct sunlight can reach in excess of 40 °C. High temperatures during the late season, leading up to harvest, can enhance susceptibility of apples to superficial scald which develops in storage. In contrast, the authors found that low temperatures in the preharvest interval could reduce susceptibility (Toivonen and Hodges 2011).
4. **Salinity**
   Tomatoes grown under high salinity will produce smaller fruit with higher soluble solids. Smaller fruit will have higher surface area to volume ratios, hence greater susceptibility to postharvest water loss i.e. desiccation stress. While there is no direct information in the literature to confirm that smaller tomato fruit from saline growing conditions would be subject to greater desiccation stress postharvest, firmness declines for tomatoes grown under 3 and 6 dS m^{-1} salinity levels were increased by 50–130 %, respectively, at 2 weeks holding at 20 °C compared with control fruit (Toivonen and Hodges 2011).
5. **Light**
   It would be considered logical to assume that effects of exposure to high light are difficult to dissociate from effects exposure to high temperatures. However, research has shown that low light (bagging of apples) in the preharvest interval reduced susceptibility of apples to developing superficial scald in cold storage and, in contrast, high ambient temperatures resulted in increased susceptibility. Generally, only sun-exposed surfaces of susceptible cultivars of apples develop scald in storage. In the case of ambient low light, when lettuce is grown under low light which is sub-optimal for photosynthetic activity, shelf life of fresh cut lettuce i.e. lettuce subjected to mechanical stress is much shorter than lettuce produced under optimal light conditions (Witkowska and Woltering 2010). Tomato size is smaller when the crop is grown under ambient low light levels, such as in the early spring season in northern latitudes (Gruda 2005) and since

surface area to volume ratio is greater in smaller fruits, susceptibility to postharvest desiccation stress would increase. Low light also results in lower levels of ascorbate in many greenhouse-grown fruits and vegetables (Gruda 2005), which would render them less fit to deal with postharvest stresses since ascorbate contents are general directly proportional to relative levels or stress tolerance (Toivonen and Hodges 2011).

II. Postharvest stresses during handling and storage

1. **Temperature extremes**
   Postharvest temperature abuse during distribution is an ongoing challenge for many products, particularly those being shipped by air or ocean container. Breaks in cool chain temperatures can result in acceleration of climacteric ripening and softening i.e. reduction in shelf potential for apples harvested and stored at the preclimacteric stage of maturity (East et al. 2008). However, those authors also found that temperature breaks had minimal effects on apples harvested and stored at post-climacteric stage of maturity. Fruit harvested at post-climacteric stages of maturity are not generally of concern to industry since those fruit have shorter storage and shelf life potential. Chilling injury susceptibility is a significant issue for many crops derived from subtropical and tropical growing regions. Generally fruits, fruit vegetables (fruits which are consumed as vegetables) and root and tuber crops are chilling sensitive (Toivonen 2011).

   There is a significant literature pertaining to chilling sensitivity of crops and much effort has been devoted to better understanding of chilling injury mechanisms and approaches to ameliorating the disorder. While there are visible (surface pitting, internal browning) and textural (accelerated softening and development of mealiness) changes often associated with chilling injury, flavor generation capacity has been shown to be a sensitive early indicator of chilling stress effects. Use of heat treatments has become popular for disinfestation and disinfection of fruits and vegetables. Appropriately applied levels of heat treatment can also induce temperature tolerance to both high and low temperatures. However, when excessively harsh heat treatments are applied, heat-induced damage can occur (Toivonen and Hodges 2011).
2. **Low O_2 and high CO_2**
   Managing postharvest handling and storage atmospheres to avoid low O_2 or high CO_2 stress is a constant concern and the problem is more severe when handling products in modified atmosphere (MA) packages as opposed to controlled atmosphere (CA) systems since temperature is often not as easily controlled in the MA packages as the produce moves through a distribution chain (Toivonen 2009). As such, the importance atmospheric stress in postharvest systems deserves significant discussion. While low O_2 levels are well-known to induce stress-induced changes in metabolism and resultant metabolite accumulations, acute low oxygen injury is not expressed until the tissue is re-aerated and a consequent uncontrolled oxygen burst (consisting of hydrogen peroxide

and other radicals) occurs, resulting in lipid peroxidation, protein denaturation and membrane injury. Different fruits and vegetables have varying thresholds for low O_2 stress, dependent on anatomy, temperature, physiological age, presence of supplemental gases e.g. CO_2, CO, SO_2, C_2H_4 and duration of exposure (Kanellis et al. 2009).

When a fruit or vegetable is converted to fresh-cut format, it generally becomes tolerant to lower levels of oxygen. One of the most notable effects of high CO_2 levels in postharvest handling is to competitively inhibit ethylene binding and action hence delaying ripening in climacteric fruits. High CO_2 will directly inhibit succinate dehydrogenase, thus impairing the functioning of the tricarboxylic acid cycle and aerobic respiration. There are numerous physiological disorders that can be attributed to high CO_2 stress, including black heart of potatoes, brown heart or core in apples and pears, surface bronzing in apples and brown stain of lettuce. High CO_2 can also modulate chilling stress, ethylene induced disorders and susceptibility to pathogenic attack (Kader and Saltveit 2003).

3. **Mechanical injury**

There are two types of mechanical injury that can be incurred during harvest and handling of fruits and vegetables; (1) cuts or punctures, and (2) impacts leading to bruises. Cuts can lead to transitory increases in respiration, ethylene production, phenolics production and cell deterioration near the site of the injury (Toivonen 2005). Several factors influence the severity and size of bruising sustained, including maturity, water potential, tissue or cellular orientation at the site of the injury, shape of the object imparting the bruising force, energy and angle of the impact, and temperature of the product (Miller 2003). Cut type injuries are most prevalent in fresh-cut fruit and vegetable products. Severity of response to cutting is very much dependant on the tissue characteristics, maturity of the fruit or vegetable of interest, the coarseness or sharpness of the cutting implement used and the temperature at which the cutting is done. Cut injuries occur during the harvest process of many fruits and vegetables and is more severe in machine-harvested as compared with hand-harvested product. Impact caused injuries are associated with loading of product for transport, events during transport (particularly when uneven or rough roads or lanes are encountered), during unloading and throughout packaging and processing lines (Miller 2003).

4. **Desiccation**

Loss of water leading to deterioration in fruit and vegetable tissues is a common issue for postharvest handling and distribution. In addition to wilting, water stress can lead to accelerated senescence or ripening which are expressed as softening of tissues, membrane deterioration and yellowing. As mentioned previously, one of the main characteristics of a fruit or vegetable that defines susceptibility to water loss is surface area to volume ratio. In beans, the density of hairs on the cuticle can modulate rates of water loss to some extent and damage to these hairs will lead to increased losses. The driving force for water loss is the vapor pressure deficit (vpd), which is the relationship that describes the difference in water activity of the fruit or vegetable and the water activity of the atmosphere surrounding it (Ben-Yehoshua and Rodov 2003). The greater the vapor pressure deficit, the greater the water loss. Three postharvest handling principles are important in minimizing water loss of any fruit or vegetable; (1) warm product loses water faster than cool product when placed into a cool room, hence the importance of rapid precooling before storage, (2) delays in cooling will lead to longer exposures to higher vapor pressure deficit conditions, hence timely cooling after harvest is of utmost importance, and (3) storing product at the coldest storage temperature and highest relative humidity possible will minimize water loss (Toivonen 2011).

Abiotic stresses are significant determinants of quality and nutritional value of fruits and vegetables during harvest, handling, storage and distribution to consumer. Crop management can have a significant influence on susceptibility to stress. In addition, climate change has created additional environmental variables which may influence postharvest stress susceptibility of fruits and vegetables. While breeding is underway for many crops to develop stress resistance that will allow them to adapt to climate change, it is not clear that breeding for stress resistance in the field will also extend stress resistance characteristics to the harvested portion. It is important understand the basis of molecular and biochemical response networks to various stresses encountered in the field and in the postharvest continuum to better evaluate the benefits that abiotic stress during production may yield for postharvest abiotic stresses. The researcher must determine whether the adaptive stress response is best tested in the field, greenhouse or test tube. In the context of postharvest handling treatments, there is some indication that such approaches may benefit in enhancing tolerance and thereby extending shelf and nutritional life of fruits and vegetables. However, again there is a limited amount of basic understanding to help guide the development of approaches to reliably confer useful levels of stress tolerance to stresses in general, and, more importantly, to specific stresses that a product is known to be subjected to during its normal distribution (Toivonen and Hodges 2011).

Therefore, it could be concluded that, abiotic stresses are significant determinants of quality and nutritional value of fruits and vegetables during harvest, handling, storage and distribution to consumer. Abiotic stresses occurring during production can either be the primary cause (direct) for disorders that exhibit themselves during postharvest handling and storage practices or they can influence the susceptibility of a fruit or vegetable to postharvest conditions that cause abiotic stresses resulting in disorders (indirect).

12 Implications of Physiology on Postharvest Handling

It is well known that, vegetables are cited as being an important part of a healthy diet. Managing retention of the quality and healthful constituents in vegetables requires a significant depth of knowledge of the postharvest physiology of these products in order to control the target processes that are responsible for constituent and quality change (Bartz and Brecht 2003). Quality is of underlying importance since poor-quality product will not be acceptable for consumption, no matter what the nutritional value of the product. There are at least three recently published entire volumes devoted to in-depth discussion of the physiology of vegetables and which provide a very detailed description of the postharvest physiology of vegetables i.e., Bartz and Brecht 2003; Lamikanra et al. 2005 and Sinha (2011).

The understanding of the physiological bases of quality retention in vegetables provides good guidance to the issues which limit the storage or shelf life of a vegetable and also good guidance to the limitations that may exist for application of certain approaches. Examples of the limitations which may exist are that sensitivity to chilling injury or high CO_2 would preclude the use of low storage temperatures or high CO_2 controlled atmospheres for such a vegetable. Therefore, it is important to define the characteristics of the vegetable in question using existing information and then develop possible strategies to enhance storage life potential as define by whatever criterion is important (sensory quality, nutritional quality, or functional quality). Low temperature storage-induced chilling injury may be more subtle in nature than development of visual defects in vegetable (Toivonen 2011). In many cases these subtle effects can be noted as changes in processing quality induced by low storage temperatures. A good example is potato which is known to sweeten in response to low temperature storage. Consequently, the storage temperature recommendations for potatoes vary significant according to the end-use cooking method. At low temperatures the storage starch is converted to sugars and therefore the potato will tend to be susceptible to unacceptable levels of browning under normal chipping conditions. Another consequence of this sweetening is on the pasting quality attributes when the potatoes are being used for potato flour starch manufacture. Low temperature storage starch loss significant reduces the pasting quality of flour made from those potatoes (Kaur et al. 2007). It is therefore, important to understand the physiological responses of vegetables to the storage conditions in direct relation to the end use for which they are intended.

Water loss is one of the most visible changes in vegetables, often being the factor that limits marketing life (Shamaila 2005). Notional estimates of threshold water loss that renders a particular vegetable unacceptable have been listed in older publications and some of these values are presented in Table 17. The table illustrates several general principles about the morphology of a vegetable and the threshold for water loss before the quality is visually unacceptable. First, bulky organs such as tubers, bulbs, head-forming leafy vegetables, and topped root vegetables have a relatively high threshold of water loss, whereas loose leafy vegetables and bunched root vegetables (i.e., vegetables having leafy tops attached) have relatively

Table 17 Classification of vegetable types by anatomical description, and maximum permissible water loss threshold for saleability of selected vegetables at commercial maturity

Vegetable type	Maximum percent water loss	Common name listing of examples
Root	4	Carrot (bunched), beet (bunched)
	7–8	Carrot (topped), beet (topped), parsnip
Bulb	10	Onion
Tuber	7	Potato (cured and immature)
Stem	8	Asparagus
Leafy	3–5	Lettuce, spinach, rhubarb
	7–10	Celery, cabbage, leek, watercress, Brussels sprout
Floral	4	Broccoli
	7	Cauliflower
Immature fruit	5	Peas, cucumber, snap beans
	7	Peppers, sweet corn
Mature fruit	7	Tomato

Adapted from Toivonen (2011)

lower threshold values for unacceptable water loss. A large part of this difference is that loose leafy structures are more prone to show wilting than bulky organs (Ben-Yehoshua and Rodov 2003).

If water loss is identified as a quality issue for vegetables, it can easily be resolved by "recharging" the vegetable with water, a practice that is prevalent via overhead misting systems in North American retail produce displays. The practice of misting is supported by research literature. It has demonstrated that water content can be increased and quality maintained by "recharging" carrots with cold water under simulated retail display conditions. Barth et al. (1990) found that misting broccoli under simulated retail conditions not only maintained visual quality, but also enhanced ascorbic acid retention. From these examples it can be seen that water loss is potentially a simple problem to resolve by "recharging;" however, if level of loss exceeds a cell injury threshold, rehydration may not be possible (Shibairo et al. 2002). Another aspect of water loss is that the size of the vegetable has a significant influence (Toivonen 2011).

Generally, smaller vegetables have a higher surface area to volume ratio (Ben-Yehoshua and Rodov 2003). Consequently, vegetables such as carrot and pepper will have greater weight loss when they are less mature and smaller in size (Dìaz-Pèrez et al. 2007). Therefore, size grades of vegetables will have differential shelf life potentials based on water loss rates. The response of an individual vegetable to controlled or modified atmosphere may determine what the optimal atmosphere is and also whether it should be co-packaged with another vegetable, even if they are closely related botanically. Selection of cultivars for their suitability for either storage or processing normally requires a complete analysis of all the physiological characteristics that define the vegetables suitability for the desired use. For example, in selecting butter head lettuce for fresh-cut use, it was established that cultivars having both lower respiration rates and lower sensitivity to high carbon dioxide injury were the most suitable. Most often there is more than one physiological characteristic that determines the overall acceptability of a vegetable cultivar for the intended use. If all the characteristics required are identified when selecting new cultivars, then there is a greater chance that that cultivar will have a consistent acceptability for that intended use over the long term. Genetic transformation platforms may provide avenues to accelerate vegetable quality improvement for fresh storage and processing uses in the future, once the molecular mechanisms for quality are better understood (Pech et al. 2005).

Therefore, it could be concluded that, vegetable quality and nutritional value are determined by the physiological characteristics of the vegetable. Suitability for end use, including storage capability, shelf life potential, and acceptability for processing either minimal or secondary processing are also very much determined by the physiological characteristics. Therefore, knowledge of the physiological profile of the selected vegetables can be a powerful tool to assist in optimizing commercial utilization.

13 Climate Changes and Potential Impacts on Vegetable Postharvest

Due to its importance around the globe, agriculture was one of the first sectors to be studied in terms of potential impacts of climate change. Many alternatives have been proposed to growers aimed at minimizing losses in yield. However, few studies have addressed changes in postharvest quality of fruits and vegetable crops associated with these alterations. Nowadays, climate changes, their causes and consequences, gained importance in many other areas of interest for sustainable life on Earth. The subject is, however, controversial.

According to studies carried out by the Intergovernmental Panel on Climate Change (IPCC), average air temperatures will increase between 1.4 and 5.8 °C by the end of this century, based upon modeling techniques that incorporated data from ocean and atmospheric behavior (IPCC 2001). The possible impacts of this study, however, are uncertain since processes such as heat, carbon, and radiation exchange among different ecosystems are still under investigation. Less drastic estimates predict temperature increase rates of 0.088 °C per decade for this century (Kalnay and Cai 2003). Other investigators forecast for the near future that rising air temperature could induce more frequent occurrence of extreme drought, flooding or heat waves than in the past (Assad et al. 2004).

In most tropical regions temperature effects were so far lower, but important changes in rain distribution has occurred in Australia, Asia and Africa. In such events monsoon weakening was observed across Asia and Africa, playing an important role by making rain more scarce and irregular, at a point that climate changes are pointed as one of the most important causes of recent famines in areas such as the Sahel region of Africa. Higher temperatures can increase the capacity of air to absorb water vapor and, consequently, generate a higher demand for water. Higher evapotranspiration indices could lower or deplete the water reservoir in soils, creating water stress in plants during dry seasons. For example, water stress is of great concern in fruit production, because trees are not irrigated in many production areas around the world. It is well documented that water stress not only reduces crop productivity but also tends to accelerate fruit ripening (Henson 2008).

Exposure to elevated temperatures can cause morphological, anatomical, physiological, and, ultimately, biochemical changes in plant tissues and, as a consequence, can affect growth and development of different plant organs. These events can cause drastic reductions in commercial yield. However, by understanding plant tissues physiological responses to high temperatures, mechanisms of heat tolerances and possible strategies to improve yield, it is possible to predict reactions that will take place in the different steps of fruit and vegetable crops production, harvest and postharvest. Besides increase in temperature and its associated effects, climate changes are also a consequence of alterations in the composition of gaseous constituents in the atmosphere. Carbon dioxide (CO_2), also known as the most important greenhouse gas, and ozone (O_3) concentrations in the atmosphere are changing during the last decade and are affecting many aspects of fruit and vegetable crops production around the globe (Lloyd and Farquhar 2008).

Carbon dioxide concentrations are increasing in the atmosphere during the last decades. The current atmospheric CO_2 concentration is higher than at any time in the past 420,000 years. Further increases due to anthropogenic activities have been predicted. Carbon dioxide concentrations are expected to be 100 % higher in 2100 than the one observed at the pre-industrial era (IPCC 2007). Ozone concentration in the atmosphere is also increasing. Even low-levels of ozone in the vicinities of big cities can cause visible injuries to plant tissues as well as physiological alterations (Felzer et al. 2007). The above mentioned climate changes can potentially cause postharvest quality alterations in fruit and vegetable crops. Although many researchers have addressed climate changes in the past and, in some cases, focused postharvest alterations, the information is not organized and available for postharvest physiologists and food scientists that are interested in better understanding how these changes will affect their area of expertise (Moretti et al. 2010).

In this section, it could be reviewed how changes in ambient temperature and levels of carbon dioxide and ozone can potentially impact the postharvest quality of fruit and vegetable crops.

I. Effects of temperature on postharvest quality of fruit and vegetable

Fruit and vegetable growth and development are influenced by different environmental factors. During their development, high temperatures can affect photosynthesis, respiration, aqueous relations and membrane stability as well as levels of plant hormones, primary and secondary metabolites. Seed germination can be reduced or even inhibited by high temperatures, depending on the species and stress level. Most of the temperature effects on plants are mediated by their effects on plant biochemistry. For plants that are subjected to water deficit, temperature is a physical facilitator for balancing sensible and latent heat exchange at the shoot, which is modulated by relative humidity and by wind. Most of the physiological processes go on normally in temperatures ranging from 0 to 40 °C. However, cardinal temperatures for the development of fruit and vegetable crops are much narrower and, depending on the species and ecological origin, it can be pushed towards 0 °C for temperate species from cold regions, such as carrots and lettuce. On the other hand, they can reach 40 °C in species from tropical regions, such as many cucurbits and cactus species (Moretti et al. 2010).

Higher than normal temperatures affect the photosynthetic process through the modulation of enzyme activity as well as the electron transport chain (Sage and Kubien 2007). Additionally, in an indirect manner, higher temperatures can affect the photosynthetic process increasing leaf temperatures and, thus, defining the magnitude of the leaf-to-air vapor pressure difference (D), a key factor influencing stomatal conductance (Lloyd and Farquhar 2008). Photosynthetic activity is proportional to temperature variations. High temperatures can increase the rate of biochemical reactions catalyzed by different enzymes. However, above a certain temperature threshold, many enzymes lose their function, potentially changing plant tissue tolerance to heat stresses. Temperature is of paramount importance in the establishment of a harvest index. The higher the temperature during the growing season, the sooner the crop will mature (Moretti et al. 2010).

Exposure of fruit and vegetable crops to high temperatures can result in physiological disorders and other associated internal and external symptoms (Table 18).

It is also well known that exposure of fruit to temperature extremes approaching 40 °C can induce metabolic disorders and facilitate fungal and bacterial invasion. Although symptoms of heat injury and disease incidence are easily observed at the end of storage, the incipient incidence of these disorders is often

Table 18 Symptoms of heat and solar injury of fruit and vegetable crops

Crop	Symptoms
Snap bean	Brown and reddish spots on the pod; spots can coalesce to form a water-soaked area
Cabbage	Outer leaves showing a bleached, papery appearance; damaged leaves are more susceptible to decay
Lettuce	Damaged leaves assume papery aspect; affected areas are more susceptible to decay; tipburn is a disorder normally associated with high temperatures in the field; it can cause soft rot development during postharvest
Muskmelon	Characteristic sunburn symptoms: dry and sunken areas; green color and brown spots are also observed on rind
Bell pepper	Sunburn: yellowing and, in some cases, a slight wilting
Potato	Black heart: occur during excessively hot weather in saturated soil; symptoms usually occur in the center of the tuber as dark-gray to black discoloration
Tomato	Sunburn: disruption of lycopene synthesis; appearance of yellow areas in the affected tissues
Apple	Skin discoloration, pigment breakdown and water-soaked areas
Avocado	Skin and flesh browning; increased decay susceptibility
Lime	Juice vesicle rupture; formation of brown spots on fruit surface
Pineapple	Flesh with scattered water-soaked areas; translucent fruit flesh

Adapted from Moretti et al. (2010)

not recognized in time to effect corrective treatment. In general, visible evidence of heat injury on tomatoes appears as yellowish-white patches on the side of fruits (Table 18).

II. Effects of CO_2 exposure on fruit and vegetable postharvest quality

The Earth's atmosphere consists basically of nitrogen (78.1 %) and oxygen (20.9 %), with argon (0.93 %) and carbon dioxide (0.031 %) comprising next most abundant gases. Nitrogen and oxygen are not considered to play a significant role in global warming because both gases are virtually transparent to terrestrial radiation. The greenhouse effect is primarily a combination of the effects of water vapor, CO_2 and minute amounts of other gases (methane, nitrous oxide, and ozone) that absorb the radiation leaving the Earth's surface (IPCC 2001). The warming effect is explained by the fact that CO_2 and other gases absorb the Earth's infrared radiation, trapping heat. Since a significant part of all the energy emanated from Earth occurs in the form of infrared radiation, increased CO_2 concentrations mean that more energy will be retained in the atmosphere, contributing to global warming (Lloyd and Farquhar 2008). Carbon dioxide concentrations in the atmosphere have increased approximately 35 % from pre-industrial times to 2005 (IPCC 2007).

Many papers published during the last decade have clearly associated global warming with the increase in carbon dioxide concentration in the atmosphere. Changes in CO_2 concentration in the atmosphere can alter plant tissues in terms of growth and physiological behavior. Many of these effects have been studied in detail for some vegetable crops. These studies concluded, in summary, that increased atmospheric CO_2 alters net photosynthesis, biomass production, sugars and organic acids contents, stomatal conductance, firmness, seed yield, light, water, and nutrient use efficiency and plant water potential (Table 19). Högy and Fangmeier (2009) studied the effects of high CO_2 concentrations on the physical and chemical quality of potato tubers. They observed that increases in atmospheric CO_2 (50 % higher) increased tuber malformation in approximately 63 %, resulting in poor processing quality, and a trend towards lower tuber greening (around 12 %). Higher CO_2 levels (550 µmol CO_2/mol) increased the occurrence of common scab by 134 % but no significant changes in dry matter content, specific gravity and underwater weight were observed. Higher (550 µmol CO_2/mol) concentrations of CO_2 increased glucose (22 %), fructose (21 %) and reducing sugars (23 %) concentrations, reducing tubers quality due to increased browning and acryl amide formation in French fries. They also observed that proteins, potassium and calcium levels were reduced in tubers exposed to high CO_2 concentrations, indicating loss of nutritional and sensory quality (Table 19).

III. Effects of O_3 exposure on fruit and vegetable postharvest quality

Ozone in the troposphere is the result of a series of photochemical reactions involving carbon monoxide (CO), methane (CH_4) and other hydrocarbons in the presence of nitrogen species ($NO+NO_2$). It forms during periods of high temperature and solar irradiation, normally during summer seasons (Mauzerall and Wang 2001). It is also formed, naturally during other seasons, reaching the peak

Table 19 Physiological and quality parameters of fruit and vegetable crops affected by exposure to increased CO_2 and the effect of O_3

Physiological or quality parameter	Effect of high CO_2	Product	Effect of O_3	Product
Photosynthesis	↑	Potato; spinach;	↓	Strawberry; conifers; hardwoods
Respiration	↓	Asparagus; broccoli; mung bean sprouts; blueberries; tomato; pears	↑	Blueberry; broccoli; carrot
	↑	Potato; lettuce, eggplant; lemons; cucumber; mango		
	=	Apple		
Firmness	=	Tomato	↑	Cucumber
	↑	Strawberry; raspberry		
Starch	↑	Potato	=	Potato
Citric Acid	↓	Potato; tomato	↑	Potato
Malic Acid	↓	Potato; tomato	↓	Potato
Ascorbic acid	↑	Potato; strawberry; orange; tomato	↓	Potato
Reducing sugars	↑	Potato; tomato	↓	Potato
Nitrate	↓	Potato; celery; leaf lettuce; Chinese cabbage	↑	Potato
Ripening	↓	Tomato		
Stomatal conductance	↓	Spinach		
Color intensity	↑	Grape		
Dry matter	↑	Potato		
Alcohol	↑	Grape; mango; pear		
Titratable Acidity	=	Grape; mango; pear		
Total phenolics	↑	Grape; strawberry		
Anthocyanins	↑	Grape; strawberry		
Glycoalkaloids	↓	Potato		
pH	=	Grape		
Volatile compounds	↓	Mango		
Antioxidant capacity	↓	Scallion; strawberry		
Visible injury			↑	Black cherry
Viscosity			↑	Potato
Electrolyte leakage			↑	Persimmon
Sucrose			=	Potato; carrot
N, P			=	Potato
K, Mg			↑	Potato

Different effects on these crops including increasing (↑) or decreasing (↓) or neutral effect (=) (Adapted from Moretti et al. 2010) of natural production in the spring. However, higher concentrations of atmospheric ozone are found during summer due to increase in nitrogen species and emission of volatile organic compounds. Concentrations are at maximum values in the late afternoon and at minimum values in the early morning hours, notably in industrialized cities and vicinities. The opposite phenomenon occurs at high latitude sites. Another potential source for increased levels of ozone in a certain region is via the movement by local winds or downdrafts from the stratosphere (Moretti et al. 2010).

The effects of ozone on vegetation have been studied both under laboratory and field experiments. Stomatal conductance and ambient concentrations are the most important factors associated with ozone uptake by plants. Ozone enters plant tissues through the stomates, causing direct cellular damage, especially in the palisade cells (Mauzerall and Wang 2001). The damage is probably due to changes in membrane permeability and may or may not result in visible injury, reduced growth and, ultimately, reduced yield. Visible injury symptoms of exposure to low ozone concentrations include changes in pigmentation, also known as bronzing, leaf chlorosis, and premature senescence (Felzer et al. 2007).

Since leafy vegetable crops are often grown in the vicinity of large metropolitan areas, it can be expected that increasing concentrations of ozone will result in increased yellowing of leaves (Table 19). Leaf tissue stressed in this manner could affect the photosynthetic rate, production of biomass and, ultimately, postharvest quality in terms of overall appearance, color and flavor compounds. Greatest impacts in fruit and vegetable crops may occur from changes in carbon transport. Underground storage organs e.g., roots, tubers, bulbs normally accumulate carbon in the form of starch and sugars, both of which are important quality parameters for both fresh and processed crops. If carbon transport to these structures is restricted, there is great potential to lower quality in such important crops as potatoes, sweet potatoes, carrots, onions and garlic. Quality attributes and sensory characteristics were evaluated on tomato fruits cv. Carousel after ozone exposure (concentration ranging from 0.005 to 1.0 μmol/mol) at 13 °C and 95 % RH. Soluble sugars (glucose, fructose), fruit firmness, weight loss, antioxidant status, CO_2/H_2O exchange, ethylene production, citric acid, vitamin C (pulp and seed) and total phenolic content were not significantly affected by ozone treatment when compared to fruits kept under ozone-free air. A transient increase in b-carotene, lutein and lycopene content was observed in ozone-treated fruit, though the effect was not consistent. Sensory evaluation revealed a significant preference for fruits subjected to low-level ozone-enrichment (0.15 μmol/mol) (Tzortzakisa et al. 2007).

Finally, it could be concluded that rising levels of CO_2 also contribute to global warming, by entrapping heat in the atmosphere. Prolonged exposure to CO_2 concentrations could induce higher incidences of tuber malformation and increased levels of sugars in potato and diminished protein and mineral contents, leading to loss of nutritional and sensory quality. Increased levels of ozone in the atmosphere can lead to detrimental effects on postharvest quality of fruit and vegetable crops. Elevated levels of O_3 can induce visual injury and physiological disorders in different species, as well as significant changes in dry matter, reducing sugars, citric and malic acid, among other important quality parameters (Moretti et al. 2010).

Therefore, it could be concluded that, exposure of fruit and vegetable crops to high temperatures can result in physiological disorders and other associated internal and external symptoms. Changes in ambient temperature and levels of carbon dioxide and ozone can potentially impact the postharvest quality of fruit and vegetable crops.

14 Postharvest Biotechnology

As an emerging technology, the plant tissue culture has a great impact on both agriculture and industry, through providing plants needed to meet the ever increasing world demand. It has made significant contributions to the advancement of agricultural sciences in recent times and today they constitute an indispensable tool in modern agriculture. Biotechnology has been introduced into agricultural practice at a rate without precedent. Tissue culture allows the production and propagation of genetically homogeneous, disease-free plant material. Cell and tissue *in vitro* culture is a useful tool for the induction of somaclonal variation. Genetic variability induced by tissue culture could be used as a source of variability to obtain new stable genotypes. Interventions of biotechnological approaches for *in vitro* regeneration, mass micropropagation techniques and gene transfer studies in tree species have been encouraging. *In vitro* cultures of mature and/or immature zygotic embryos are applied to recover plants obtained from inter-generic crosses that do not produce fertile seeds. Genetic engineering can make possible a number of improved crop varieties with high yield potential and resistance against pests. Genetic transformation technology relies on the technical aspects of plant tissue culture and molecular biology for:

- Production of improved crop varieties.
- Production of disease-free plants (virus).
- Genetic transformation.
- Production of secondary metabolites.
- Production of varieties tolerant to salinity, drought and heat stresses.

The past decades of plant cell biotechnology has evolved as a new era in the field of biotechnology, focusing on the production of a large number of secondary plant products. During the second half of the last century the development of genetic engineering and molecular biology techniques allowed the appearance of improved and new agricultural products which have occupied an increasing demand in the productive systems of several countries worldwide (James 2008). Nevertheless, these would have been impossible without the development of tissue culture techniques, which provided the tools for the introduction of genetic information into plant cells. Nowadays, one of the most promising methods of producing proteins and other medicinal substances, such as antibodies and vaccines, is the use of transgenic plants. Transgenic plants represent an economical alternative to fermentation-based production systems. Plant-made vaccines or antibodies (plantibodies) are especially striking, as plants are free of human diseases, thus reducing screening costs for viruses and bacterial toxins. The number of farmers who have incorporated transgenic plants into their production systems in 2008 was 13.3 million, in comparison to 11 million in 2007.

Plant cell culture has made great advances. Perhaps the most significant role that plant cell culture has to play in the future will be in its association with transgenic plants. The ability to accelerate the conventional multiplication rate can be of great benefit to many countries where a disease or some climatic disaster wipes out crops. The loss of genetic resources is a common story when germplasm is held in field gene banks. Slow growth *in vitro* storage and cryopreservation are being proposed as solutions to the problems inherent in field genebanks. If possible, they can be used with field gene banks, thus providing a secure duplicate collection. They are the means by which future generations will be able to have access to genetic resources for simple conventional breeding programs, or for the more complex genetic transformation work. As such, it has a great role to play in agricultural development and productivity (Hussain et al. 2012).

Fruits, being highly nutritive, are important component of human diet but they possess very short post-harvest shelf life. As ripen, they become very soft and more prone to injuries, which make them highly perishable. Over 30 % of the annual produce in India is wasted due to spoilage. Hence, there is an urgent need to develop technologies to overcome post-harvest losses of fruits. Physiologists and biochemists attempted to extend the shelf life of fruits by different means though the results were not very satisfying. It was demonstrated recently that a judicious dose of γ-irradiation (0.1–0.5 kGy) could enhance the shelf life to fruits by about a week to a fortnight, which could help in minimizing the spoilage during storage and transportation. However, stringent quality controls have to be strictly followed to get the best results. Studies revealed that γ-irradiation brings alterations/changes in metabolic pathways, which delay the production of essential precursors and energy required for ripening of fruits. Another strategy, to enhance the shelf life of fruits, could be adopted through regulation of endogenous ethylene production. Most recent studies have shown that it could be achieved by such genetically modified (GM) crops where gene expression of key enzymes responsible for ripening, like PG-ase, EFE and ACC-synthase, by means of antisense RNAs. However, adoption of this technology has so far been deterred due to apprehensions of safety issues associated with GM crops. An alternate method for prevention of spoilage of fruits as well as sustaining the interests in farmers could be the value addition of fruit commodities. This could be achieved by improving the conventional methods as well as development of non-conventional products of commercial interest (Surendranathan 2005).

Fruits become susceptible to damage on ripening for they soften drastically. A ripened fruit, depending on the variety, has a limited shelf life of a few days to

1 or 2 weeks. Besides, the soft and fleshy nature makes a ripened fruit more susceptible to injuries, increasing the losses further due to spoilage. Hence, it is necessary to develop appropriate technology and infrastructure for proper storage and transportation of the fruits. One of the reasons for the low commercial activity in the fruit and vegetable sector is the lack of organized cultivation. As a result, the total domestic production of fruits and vegetables reaches only domestic market. Many a times, fruits like Indian local varieties of mangoes, bananas, etc., do not attract commercial interests due to lack of proper postharvest management. Some fruits like jackfruits and cashew apple are under-utilized to the extent of 80 % and spoiled as they fall around the tree causing environmental problems. Thus, there is an urgent need to develop technologies to overcome postharvest losses of fruits. One way of achieving this could be by developing feasible technology to extend the postharvest shelf life. Another alternative is the value addition of the produce by developing innovative products of consumer interest. For either of these, it is important to have a fair assessment of the available technologies as well as an understanding of the physiology and biochemistry of fruits ripening (Surendranathan 2005).

Therefore, it could be concluded that, there is an urgent need to develop technologies to overcome post-harvest losses of fruits. Physiologists and biochemists attempted to extend the shelf life of fruits by different means though the results were not very satisfying. It was demonstrated recently that a judicious dose of γ-irradiation (0.1–0.5 kGy) could enhance the shelf life to fruits by about a week to a fortnight, which could help in minimizing the spoilage during storage and transportation.

15 Conclusion

The fruit processing industry is one of the major businesses in the world. While basic principles of fruit processing have shown only minor changes over the last few years, major improvements are now continuously occurring, and more efficient equipment capable of converting huge quantities of fruits into pulp, juice, dehydrated, frozen, refrigerated products, etc. make possible the preservation of products for year-round consumption. The fruit processing and storage, even under the most industrially available "mild conditions," involves physical and chemical changes that negatively modify the quality. Postharvest management is a set of post-production practices that includes: cleaning, washing, selection, grading, disinfection, drying, packing and storage. These eliminate undesirable elements and improve product appearance, as well as ensuring that the product complies with established quality standards for fresh and processed products. There is an urgent need to develop technologies to overcome postharvest losses of fruits. One way of achieving this could be by developing feasible technology to extend the postharvest shelf life.

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