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Preface

Excellent fruits with delicate nature, health benefits, and market acceptability belong to the temperate regions of the world. Once harvested, these fruits must be handled with proper care. Maintaining the postharvest quality of temperate fruits has long been a challenging task. This book presents technologies that are in use, or have the potential to be used, to maintain the postharvest quality. In this book, we have sincerely attempted to provide comprehensive coverage of various aspects, particularly postharvest biology and technology of temperate fruits, in different chapters authored by experts in the field.

This is arguably one of the first books focusing on postharvest handling and technology of temperate fruits. This book focuses on the biodiversity of temperate fruits, orchard management, nutritional and health benefits, and postharvest technologies for shelf-life enhancement. The contributing authors address the postharvest biology and technology of individual temperate fruits, such as plum, cherry, peach, apricot, apple, pear, quince, loquat, kiwi, persimmon, berries, and strawberry. Contributions from experts in the field make this a key reference material for all aspects of postharvest management of temperate fruits.

We believe that this comprehensive collection will benefit students, scientists, postharvest technologists, professionals in the fruit industry, and many others. We are grateful to all the contributors for promptly submitting their chapters. We also thank the staff of the editorial and production departments of Springer for their unstinted support and efforts to bring about this book in its present form.

Awantipora, India — Shabir Ahmad Mir
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Biodiversity of Temperate Fruits

Aejaz Ahmad Dar, Reetika Mahajan, Padma Lay, and Susheel Sharma

Introduction

Many of the world's well-known fruits (apple, pear, peach, plum, grape, and strawberry) that grow in particular environments found in regions with Mediterranean climate are known as temperate fruits. These areas include California (USA), North Africa, Turkey, the Middle East, southern Europe, Greece, Central Chile, Australia, and some parts of Asia. These fruits can adapt well in two different climatic conditions, where they undergo a dormancy period to complete their cycle. This dormancy period helps the fruit to adapt well in tropical climates, and they have various degrees of winter hardiness, which helps the fruits to adapt cold conditions (Encyclopedia of Food and Culture 2003; Retamales 2011). Fruits are considered a valuable food commodity with many potential health benefits due to the presence of natural antioxidant components, which can contribute to the prevention of cardiovascular and other chronic diseases, such as heart disease, cancer, diabetes, and Alzheimer's disease. It has been revealed that carotenoids and polyphenols, such as anthocyanins, flavonoids, phenolics, and phenylpropanoids, present in fruits might act as antioxidants and therapeutic agents contributing to such action (Manzoor et al. 2012; Khomdram et al. 2014).

The major temperate fruit crops, viz., apple, peach, cherry, plum, apricot, and pear, belong to the Rosaceae family. Most of these woody perennials have a long intergeneration period because of their large plant sizes and juvenile phase, which make them poorly suited for classical genetic analysis. On the other hand, fruit trees also possess some advantageous features, such as long life, possibility of producing interspecific crosses, existence of efficient methods of vegetative reproduction, and a smaller genome size. The breeding methods used in these temperate fruits have undergone minor changes over the last 50 years. The incorporation of specific

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alleles from wild or exotic materials into elite breeding lines has rarely produced new commercial cultivars. The knowledge provided by advances in molecular genetics, notably molecular markers, provides faster and more efficient approaches of cultivar improvement (Dirlewanger et al. 2004).

Geographical Location, Cultivation, and Production of Temperate Fruit Crops

Based on the climate conditions, temperate fruits can be classified into two categories. The first category includes fruits such as apple, pear, plum, cherry, etc. which can grow well in cold conditions, while the second category includes fruits such as peach, plum, apricot, etc. which can also grow in warmer climates. The proper development of these fruits depends on soil conditions also. Different fruits require different soil conditions, like type, pH, fertilizers, etc. Here, in this section, a brief about the cultivation practices of a few of the temperate fruits is given. The geographical distribution, production, and major common diseases of temperate fruits are presented in Table 1.

Factors Affecting the Growth of Temperate Fruit Crops and Their Production

For successful growing of temperate fruit crops, various components of climate, such as temperature, humidity, light, rainfall, hail, and frost, should be carefully studied. Man cannot control these environmental factors. It is not possible to make any changes to them. However, the effect of these factors can be altered. For these, we can take certain steps to increase or decrease the effects, i.e., the effects of high or low temperatures can be altered, additional moisture can be provided, high wind velocity can be reduced by growing a wind break around the orchard. The climate of a particular region is mainly influenced by different factors, viz., latitude, altitude, topography, position related to continents and oceans, and large-scale atmospheric circulation patterns.

Temperature

Temperature is one of the most important components of climate. It plays a vital role in the production of temperate fruit crops. There are various different activities of plants, like growth and development, respiration, photosynthesis, transpiration, uptake of nutrients, water and reproduction (such as pollen viability, blossom fertilization fruit set, etc.), carbohydrate and growth regulators balance, rate of maturation, senescence, quality, yield, and shelf life of the edible products.

Table 1 Geographical distribution, production, and common diseases of temperate fruits

S. no.	Fruit	Geographical distribution (top five countries)	Worldwide production (in MT) (FAO 2014)	Disease
1	Apricots	Armenia, Afghanistan, Iran, Italy, Turkey	3.36	Brown rot of blossom/fruit and twig blight, shot hole disease, jacket rot, bacterial canker and *Eutypa* dieback disease, *Armillaria* root rot, *Phytophthora* root and crown disease, and crown gall disease
2	Figs	Turkey, Egypt, Algeria, Morocco, Iran	1.14	Surface mold or *Alternaria* rot, fig endosepsis, brown rot, internal rot, eye-end rot, pink rot, or soft rot Fig mosaic virus, *Aspergillus* rot, limb blight or dieback, smut, sour rot
3	Pears	China, Argentina, United States, Italy, Turkey	25.79	Fire blight, pear scab, *Pseudomonas* blossom blast and canker, crown gall, powdery mildew, black rot, black Spot
4	Peaches and nectarines	China, Spain, Italy, United States, Greece	22.79	Bacterial canker, bacterial spot, crown gall, phony disease, *Alternaria* rot, brown rot, *Phytophthora* crown and root rot
5	Apples	China, United States, Turkey, Poland, India	84.63	Fire blight, *Alternaria* blotch, apple blotch, apple canker, apple scab, cedar apple rust, crown rot, powdery mildew, woolly apple aphid, rosy apple aphid, and rosy curling aphid
6	Quinces	Turkey, China, Uzbekistan, Morocco, Iran	0.64	Quince leaf blight, cedar-quince rust, fire blight
7	Plums	China, Serbia, Romania, Chile, Turkey	11.28	Plum leaf spot, plum pox virus, plum pockets, crown gall, brown rot, black knot of plum
8	Raspberries	Russia, Poland, United States, Serbia, Mexico	0.61	Spur blight, cane blight and anthracnose, raspberry leaf spot, *Botrytis* fruit rot
9	Gooseberries	Germany, Russia, Poland, Ukraine, United Kingdom	0.17	Anthracnose, powdery mildew, leaf spot, cane blight or wilt, *Botrytis* dieback and gray mold berry rot, white pine blister rust
10	Strawberries	United States, Mexico, Turkey, Spain, Egypt	8.11	Angular leaf spot, bacterial wilt, cauliflower disease, *Alternaria* fruit rot, anthracnose and anthracnose fruit rot and black spot, black root rot, gray mold, leather rot, hard rot, leak, leaf blotch
11	Blueberries	United States, Canada, Poland, Germany, Mexico	0.53	Mummy berry, *Phomopsis* twig blight, *Phomopsis* canker, *Phomopsis* leaf spot and fruit rot, *Botryosphaeria* stem blight, bacterial blight/canker, gray mold
12	Persimmons	China, Korea, Spain, Japan, Brazil	5.19	*Armillaria* root rot, gray mold, leaf spots and blights, root and crown rot, wood decay or heart rots
13	Kiwifruit	China, Italy, New Zealand, Chile, Greece	3.44	Bacterial blossom blight, oak root fungus, *Phytophthora*, bleeding canker, gray mold

Top five countries data taken from www.mapsofworld.com, Production data taken from FAO (2014)

These functions of the plant should be ideal when the temperature is in the optimum range. During high temperatures, plants do not perform proper functions of growth, while at low temperatures, the physiological activities of plants are stopped. According to the different temperature ranges in the tropics, specific trees are grown in different locations, e.g., apple, pear, peach, and almond are successfully grown in regions of low temperature, known as temperate fruits. In warm winter areas, due to insufficient chilling temperature, fruit trees fail to complete their physiological rest period or meet their chilling requirements. As a consequence, buds remain dormant, and leaves and blossoms do not appear on the trees in the following spring. For this reason, temperate fruits like apple, apricot, pear, and plums are not considered suitable for tropical or subtropical regions.

The activities of the plant are affected by very high or very low temperatures. The temperature ranges are given below:

Minimum: 4.5–6.5 °C (40–43 °F)
Optimum: 24–27 °C (75–85 °F)
Maximum: 29.5–45.4 °C (85–114 °F)

Effect of Low Temperatures

Low temperatures have adverse influences on fruit trees. There are many effects of low temperatures, i.e.:

- **Desiccation**: Imbalance between absorption rate and transpiration rate
- **Chilling injury**: There is a disturbance in the metabolic and physiological process
- **Freezing injury**: Termed as undercooling protoplasm coagulation

Chilling Requirements

Chilling is needed for fruit crops that fall dormant in the winter in order to avoid frost injury and they do not resume their growth until a certain amount of chill has accumulated for fulfilling their chilling requirements. Climate change is likely to affect the chilling requirements of temperate fruit crops significantly and, therefore, the opportunity to meet this requirement will be reduced as the climate becomes warmer. The results of these climate changes are clearly apparent in the shifting of apple cultivation from lower elevations to higher altitudes in India. Insufficient chilling greatly influences flower initiation and fruit coloration, along with deterioration in fruit texture and taste. High temperatures and moisture stress increase sunburn and cracking in apples, apricots, and cherries in the higher altitudes. Insufficient chilling reduces pollination, fruit set, and, ultimately, the yield in walnuts, pistachios, and peaches. Low temperatures in the winter are important for fulfilling their chilling requirements to ensure uniform flowering, fruit set, and generate economically sufficient yields. In order to escape certain damages of tissues from low temperatures, fruit trees of temperate or cold climates have evolved

the mechanism of dormancy. After a certain duration of cold temperature (chilling), endodormancy is inhibited and the tree is ready to resume its growth cycle in the following spring (Luedeling et al. 2011).

Humidity and Frost

The atmospheric humidity plays a vital role in deciding the amount of moisture needed to produce a fruit crop. In hot and dry weather, an enormous amount of water is lost through transpiration. If the atmosphere is humid, even though hot, the amount is much smaller and, thus, a site in a humid belt needs less irrigation. High humidity combined with high temperature also promotes rapid growth and higher yield, but increases the incidence of pests and diseases. The water requirements of a plant also depends on humidity, but, generally, the requirements for water differ as per different plant species, e.g., to produce 1 kg of apples requires 250 L of water. The plant gets water from soil, but there are many factors affecting this process, i.e., (a) amount of water in the soil, (b) the availability of water also depends on the texture and structure of the soil, (c) water absorbing area of the tree. Water is lost from the plant through transpiration by leaves. Transpiration depends on humidity, temperature, wind, light, etc., and is necessary to maintain the health of the plant by maintaining the balance between the uptake and loss of water.

Light

Light is an electromagnetic radiation which is a form of kinetic energy (Fig. 1). It comes from the sun to the Earth as discrete particles called quanta or photons. Light is one of the most important factors affecting plant life. It is an integral part of the

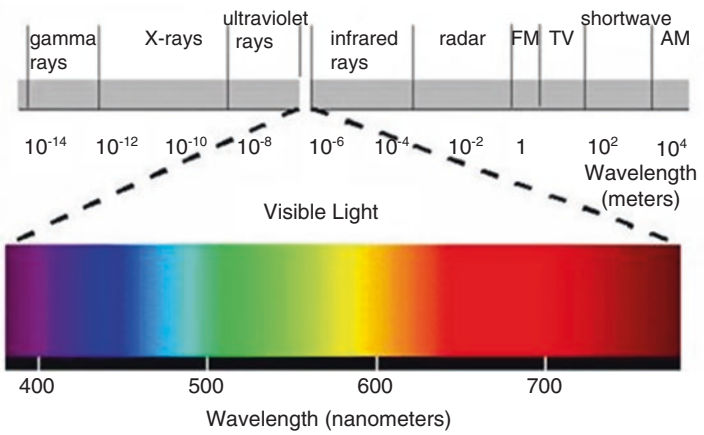

Fig. 1 Visible light spectrum showing different colors corresponding to different wavelengths of visible light

photosynthetic reaction, in which it provides the energy for the combination of carbon dioxide (CO_2) and water (H_2O) in the green cells having chlorophyll for the formation of carbohydrates with the release of oxygen. The following equation illustrates the oxidation of water during photosynthesis:

$$CO_2 + 2H_2O \rightarrow CH_3O + H_2O + O_2$$

$$6CO_2 + 13H \xrightarrow[\text{chlorophyll}]{\text{Light, radiation energy}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

The crop growth performance of plants is mainly influenced by (a) the quality of light and (b) the intensity of light:

(a) **Light intensity**

Light intensity refers to the number of photons falling on a given area or to the total amount of light which plants receive; the intensity of light varies with day, season, distance from the equator, dust particles and water vapor in the atmosphere, slope of the land, and elevation. Symptoms associated with low light intensity are decrease in the rate of photosynthesis with normal rates of respiration, decrease in supplies of carbohydrates for growth and yield, leaf tips become discolored, leaves and buds drop, leaves and flowers become light in color. With high light intensity, the plant wilts and light-colored leaves may become gray in color due to the reduction in chlorophyll, and the rate of photosynthesis is lowered while respiration continues. All the above reasons can cause low yields.

(b) **Quality of light**

This refers to the length of waves. The visible part of the spectrum of electromagnetic radiation ranges from 390 to 730 nm in wavelength. It is also called photosynthetically active radiation.

In general, red and blue light produce a greater dry weight, whereas green light inhibits plant growth. Red light promotes seed germination, growth, and flower bud formation in long day/short night plants. Photosynthesis is greater in the red region. In apple, the blue-violet region is more important for the development of red pigments and color.

Rainfall

Rainfall is a very important factor for temperate fruit crops if an orchard is to be established in a new area. It is essential that the pattern of rainfall in the prospective region be studied before any decision is made concerning the types of crop to be cultivated. Well-distributed and consistent rainfall is always desirable for an ideal orchard site. Rain at the time of flowering is not suitable, because most fruit crops are sensitive to rain.

Biodiversity of Temperate Fruit Crops

Diversity is an essential raw material for evolution, which enables populations of the crop species to survive, adapt to new circumstances, and evolve to produce new genetic variants (Gerrano 2010). Genetic diversity arises due to differences between individuals that can be visualized as variations in the DNA sequence, biochemical properties (isoenzyme structure or properties), physiological characteristics (abiotic stress resistance), and morphology (Goncalves et al. 2009). Diversity estimates also provide conservation techniques and enable the careful selection of plant material for breeding programs. Diversity within a given plant population is said to be a product of biotic factors, the physical environment, artificial selection and plant characters such as size, mating system, mutation, migration, dispersal, and the influence of man through domestication and selection (Frankel et al. 1995).

Morphological Diversity

Temperate fruit crops vary from stone to berry fruits, with wide variation within the fruit crops. The variation in a particular fruit crop can be studied in terms of phenotypically, morphologically, biochemically, and genotypically. To identify different varieties with the same name, it is important to perform primary characterization of varieties for the proper management of plant genetic resources (Hend et al. 2009; Rao et al. 2010). Morphological characterization like color, size, and shape of the fruit allows the scientist to study variation in fruits by using visual attributes and have been widely used to discriminate between varieties of the same species (Cantini et al. 1999; Barranco and Rallo 2000). Morphological traits are affected by environmental conditions such as rainfall or solar radiation (Rotondi et al. 2003). Therefore, these traits are less reliable for studying the diversity in plants. However, on one hand, plant breeders are more interested in studying the diversity of a particular crop at the molecular level, but on the other hand, farmers believe that morphological and agronomic variation is best for attaining sustainable farming (Dempsey 1996). The utilization of morphological markers is the first and simplest method of evaluating crop diversity, which should be done before molecular characterization (Hoogendijk and Williams 2001). Chalak et al. (2006) characterized peach cultivars of Lebanon at the molecular and morphological levels for the first time. The results of this study revealed that flowering dates, maturity dates, fruit type, and flesh color had significant contributions to the total variation. Principal component analysis was used to study the morphological characters, viz., flowering time, time of harvesting, size and shape of fruit, percentage of russeting, and firmness of the flesh, to identify the main origins of pear cultivar variability collected from Spain (Pereira-Lorenzo et al. 2012). Pérez-Romero et al. (2015) studied the morphological and molecular characters of apples grown in Spain for diversity analysis and observed wide variation among morphological traits, such as diameter,

primary fruit height, and shape. Wide morphological variation has been observed in cherry based on the height of cherry rootstock (Ganji Moghadam et al. 2006). In the case of plum fruit, tree growth and pomological traits are important for studying morphological variation (Hend et al. 2009; Aran et al. 2012). Morphological characterization revealed a large diversity among almond accessions of Lebanon (Chalak et al. 2007). Thus, it can be concluded that the high diversity of the cultivars analyzed suggests a diverse origin of tropical fruit grown worldwide and have an important role in preserving endangered plant material for future use in breeding programs (Pérez-Romero et al. 2015).

Biochemical Diversity

Over the last few decades, people have become very conscious of their health and diet. In such a time, the importance of fruits for nutrition and their health benefits cannot be ignored. Fruits are the oldest food of mankind and abound with vitamins A, B, and C, and minerals like calcium, magnesium, iron, and potassium, as well as being a rich source of energy. These vitamins and minerals function as antioxidants, phytoestrogens, and anti-inflammatory agents (Slavin 2012). The antioxidant compounds, such as tocopherol, ascorbic acid, glutathione, and carotenoids, provide protection against oxidative damage from reactive oxygen species (Bloknina et al. 2003). The antioxidants work by scavenging reactive oxygen species, inhibiting their formation, and preventing the formation of hydroxyl radicals and decomposition of lipid hydroperoxides (Niwa et al. 2001). Nutritionists advise us to consume at least 115 g of fruit every day for a balanced diet. In many countries, people eat fruits as their staple food. For example, people in the South American countries eat bananas as the main course of their meal (Kazi et al. 2015). Fruits can also increase our digestive power. An intake of fruit every day keeps us hale and hearty. Phosphorus and amino acids are abundant in apple, almond, etc. Citrus fruits and aonla are rich in vitamin C, while the richest source of vitamin C is Barbados cherry. Dry apricot is the richest source of calcium, phosphorus, and niacin. Additionally, fruits supply dietary fiber, and fiber intake is linked to a lower incidence of cardiovascular disease and obesity. It was also reported that a high consumption of fruits can help in preventing several non-communicable diseases, such as cardiovascular diseases, type 2 diabetes, and cancer (Ganry 2006).

Rapid progress has been made in plant molecular biology and biotechnology, which has opened up challenging possibilities in characterizing and evaluating biochemical diversity for estimating the nutrition profile of different temperate fruits for the benefit of mankind. The varied nutritional profile of different temperate fruits grown across the globe is shown in Table 2. The nutritional composition and content can also vary between the different genotypes and varieties of the same fruit. The biochemical parameters and antioxidant profiles of nine different genotypes of strawberry fruit were characterized and variation was observed in the total flavonoid, anthocyanin, vitamin C, and folate contents (Tulipani et al. 2008).

Table 2 Nutritional composition of different temperate fruits per 100 g

Fruit	Water (%)	Energy (Kcal)	Fiber (g)	Carbo hydrate (g)	Sugar (g)	Fat (g)	Protein (g)	Vitamin A (mg)	Vitamin B1 (mg)	Vitamin B2 (mg)	Vitamin B6 (mg)	Vitamin C (mg)	Vitamin E (mg)	Sodium (mg)	Potassium (mg)	Calcium (mg)	Iron (mg)
Apple	86.00	52.00	2.40	13.80	10.39	0.17	0.26	2.00	0.02	0.03	0.04	4.60	0.18	1.00	107.00	6.00	0.12
Apricot	86.00	48.00	2.00	11.00	9.00	0.40	1.40	420.00	0.03	0.04	0.05	10.00	0.89	1.00	259.00	13.00	0.40
Blueberry	84.00	57.00	2.40	14.50	9.96	0.33	0.74	0.00	0.04	0.04	0.05	9.70	0.57	1.00	77.00	6.00	0.28
Blackberry	85.00	43.00	5.30	9.61	4.88	0.49	1.39	30.00	0.02	0.03	0.03	21.00	1.17	1.00	162.00	29.00	0.62
Cranberry	87.00	46.00	4.60	12.20	4.00	0.13	0.39	0.00	0.01	0.02	0.06	13.30	1.20	2.00	85.00	8.00	0.25
Cherry	82.00	63.00	2.10	16.00	12.80	0.20	1.10	40.00	0.03	0.03	0.05	7.00	0.10	0.00	222.00	13.00	0.36
Elderberry	80.00	73.00	7.00	18.40	0.00	0.50	0.66	0.18	0.07	0.06	0.23	36.00	0.00	0.00	280.00	38.00	1.60
Fig	80.00	74.00	2.90	19.18	16.26	0.30	0.75	3.00	0.06	0.05	0.11	2.00	0.00	1.00	242.00	35.00	0.37
Gooseberry	88.00	44.00	4.30	10.18	0.00	0.58	0.88	0.00	0.04	0.03	0.08	27.70	0.37	1.00	198.00	25.00	0.31
Grape	83.00	69.00	0.90	18.10	15.50	0.16	0.72	0.00	0.07	0.07	0.09	3.20	0.19	2.00	191.00	10.00	0.36
Kiwifruit	84.00	61.00	3.00	14.66	9.00	0.52	1.10	5.00	0.03	0.02	0.06	92.70	1.46	3.00	312.00	34.00	0.31
Mulberry	88.00	43.00	1.70	9.80	8.10	0.39	1.44	0.00	0.03	0.10	0.05	36.40	0.87	10.00	194.00	39.00	1.85
Peach	89.00	39.00	1.50	9.54	8.39	0.25	0.91	15.00	0.02	0.03	0.02	6.60	0.73	0.00	190.00	6.00	0.25
Pear	84.00	57.00	3.10	15.23	9.75	0.14	0.36	0.00	0.01	0.03	0.03	4.30	0.12	1.00	116.00	9.00	0.18
Plum	87.00	46.00	1.40	11.42	9.90	0.28	0.70	18.00	0.03	0.03	0.03	9.50	0.26	0.00	157.00	6.00	0.17
Quince	84.00	57.00	1.90	15.30	0.00	0.10	0.40	0.00	0.02	0.03	0.04	15.00	0.00	4.00	197.00	11.00	0.70
Raspberry	86.00	53.00	6.50	11.94	4.42	0.65	1.20	0.00	0.03	0.04	0.05	26.20	0.87	0.00	151.00	25.00	0.69
Strawberry	91.00	33.00	2.00	7.68	4.89	0.30	0.67	10.00	0.02	0.02	0.05	58.80	0.29	1.00	153.00	16.00	0.41

Source: USDA Nutrient Database (USDA National Agricultural Statistics Service 2014), Kazi et al. (2015)

Belakud et al. (2015) reported the highest total sugar content (7.23%) in Belruby and the highest ascorbic acid content (50%) in the fruits of cv. Sweet Charlie.

Similar variations of biochemical contents between different apple cultivars was observed and it was reported that Golden Delicious had the minimum flavonoid content when compared to Red Delicious, Granny Smith, and Reinette apples (Escarpa and Gonzalez 1998). Hammerstone et al. (2000) analyzed the biochemical variation in different apple cultivars and found that Red Delicious and Granny Smith had the maximum procyanidin content, whereas the varieties Golden Delicious and McIntosh had the minimum contents. Jonagold apples were believed to contain the highest concentration of catechins, quercetin glycosides, and chlorogenic acid than Cox's Orange Pippin, Golden Delicious, and Elstar apples (Van der Sluis et al. 2001).

The variation in the nutritional composition of 16 plum genotypes growing at different locations of Pakistan was studied by Nisar et al. (2015). Their results suggested that the genotypes differed in their nutritional composition of fruits, anthocyanin, phenolic contents, and antioxidant activity of fruits. The vitamin C content in plum genotypes ranged between 52.51 and 137.6 mg/kg, the total sugar content from 67.17 to 105.07 g/kg, the anthocyanin content from 14.23 to 212.38 mg/100 g, and the total phenolic content ranged from 2.63 to 7.62 mg/g.

The findings of Kan et al. (2014) indicated that a higher content of phenolic compounds and vitamins was found in apricot fruits grown in irrigated conditions. The Cataloglu cultivar had the highest rutin contents and the Hacihaliloglu cultivar contained the highest chlorogenic acid content in both irrigated and dry farming conditions. Vitamin C content was found to be higher than β-carotene, retinol, vitamin E, and lycopene contents in apricot fruits in both irrigated and dry farming conditions.

The biochemical variation of minerals, phenolics, and antioxidant activity in peel and pulp extracts of different genotypes of peach was studied by Manzoor et al. (2012). They observed that peach peel had significantly higher levels of minerals, antioxidant capacity, and phenolics than peach pulp, suggesting that the intake of unpeeled peach in the diet could act as a valuable source of high-value nutritional components and natural antioxidants for nutraceutical applications. Later, Liu et al. (2015a) studied the variation of nutrients in peach blossoms at different developmental stages and reported that total phenolics and flavonoids contents and antioxidant capacities were decreased during blossom development.

The highest content of organic acids, vitamin C, phenol, and flavonoids in indigenous pear cultivars were found in Karamut (0.44%), Gradišćanka (1.61 mg/100 g), Poljakinja (717.08 mg gallic acid equivalent/100 g of fresh fruit), and Mioljnjača cultivars (120.20 mg catechin equivalent/100 g of fresh fruit), respectively. The researchers observed the strongest antioxidant activity in cv. Karamut (Đurić et al. 2015).

Karlidag et al. (2009) studied six wild-growing sweet cherry genotypes with different fruit skin color, which were analyzed for their antioxidant activity, ascorbic acid contents, total anthocyanins, and total phenolic and total soluble solid contents. They found that the antioxidant activity was relatively higher in blackish skin colored

fruits than light ones. The total antioxidant activity ranged from 51.13 to 75.33%, whereas the total phenolic content was between 148 and 321 mg gallic acid equivalents (GAE)/100 g FW. Vitamin C was found to be highest in blackish colored fruits (21–27 mg/100 mL). The total soluble solid content varied between 19.35 and 23.98%.

Çağlarırmak (2003) carried out a beautiful study by investigating kernel properties and the composition of Turkish walnut genotypes. He found that Sebin Type-I and Güvenli showed good quality. These genotypes contained 6.9% palmitic acid, 7.5% stearic acid, 21.2% oleic acid, 43.4% linoleic acid, 6.3% linolenic acid, and 11.8% arachidic acid. The proximate components were protein (13.8%), ash (1.8%), moisture (3%), fat (62.8%), and carbohydrates (18.7%). The mineral components were phosphorus (316 mg/100 g), potassium (270 mg/100 g), calcium (85 mg/100 g), magnesium (90 mg/100 g), and iron (2.9 mg/100 g).

The study regarding the biochemical nutritional variability of temperate fruits will increase our knowledge for a better understanding of broadening the gene pool available for plant breeding programs to produce new varieties with superior biochemical and pomological characteristics. The selection of high quality fruit genotypes could help us to reduce fruit-related malnutrition issues in the human diet.

Genetic Diversity

Genetic diversity refers to the variability in heritable characters observed among individuals of a population (Kremer et al. 1998). The ultimate source of genetic diversity is gene mutations causing permanent change in the DNA sequence, molded and shaped by selection, recombination, gene flow, genetic drift, and migration in heterogeneous environments in space and time (Hartl and Clark 1997). Given the threat of abiotic and biotic stresses leading to crop loss, it is, thus, important to understand the genetic diversity in plant genetic resources and conserve it efficiently (Zhang et al. 2000). Further genetic diversity is vital in plant breeding programs for developing high yielding varieties and protecting the productivity of such varieties by integrating genes for disease and pest resistance or tolerance to abiotic stresses (Allard 1999). Research in plant genetics is focused on determining the amount of genetic variation in natural and domestic populations and developing methods for maintaining such variability to tackle the changing global environment (Gerrano 2010).

In a country with highly varied agroecological and diverse growing conditions, the availability of genetic diversity is significantly important for the maintenance, conservation, and enhancement of productivity in fruit crops. Such diversity has been providing security for farmers against biotic and abiotic stresses. Genetic diversity and the advent of molecular marker technologies offer great potential to add to the genetic improvement in temperate fruit breeding programs. Estimates of genetic diversity using new molecular tools, especially molecular markers, have proven to be useful in delineating heterotic groups already existing or to identify new ones (Casa et al. 2002).

DNA markers are commonly used for estimating genetic diversity in temperate fruit crops. RAPD, RFLP, and AFLP clearly distinguished the different stone fruit cultivars present in the international fruit market. RFLP markers developed for European and North American apricots produce unique profiles for most cultivars. Spanish cultivars cluster together, distinct from the remaining European and North American apricots (Hurtado et al.2001; Romero et al. 2003). Recently, microsatellite or single sequence repeat (SSR) markers have been developed for peach (Cipriani et al. 1999), apricot (Messina et al. 2004), and applied for the characterization of cultivars and confirmation of geographic origin.

Warburton and Bliss (1996) analyzed 136 peach cultivars with RAPDs from different geographical origins. The genotypes were clustered into 12 main groups and nine of these clusters comprised Asian cultivars, while the European and American cultivars were grouped into three clusters, revealing less genetic diversity. Initially, for the analysis and classification of the major apricot, cultivars a group of 190 accessions were analyzed with ten newly developed microsatellite loci (Messina et al. 2004). The genetic distance was reflected in the grouping of cultivars in agreement with their geographic origin and pedigree.

Pinar et al. (2013) determined the genetic diversity in 57 Turkish apricot genotypes using 19 sequence-related amplified polymorphism (SRAP) primers and reported 87 amplified fragments with 64% polymorphism. Cluster analysis classified the 57 genotypes into three major groups with similarity ratios among genotypes between 0.73 and 0.94. Their study revealed that the SRAP marker system can be useful for genetic diversity analysis and identification of wild-grown apricots.

Yamamoto et al. (2001) identified 36 pear accessions that included Japanese pears, Chinese pears, and European pears. Liu et al. (2015b) studied the genetic diversity in 385 pear genotypes by using 134 SSR markers. A total of 690 alleles were produced at an average of 5.45. The clustering relationship divided the genotypes into three groups, with the primary division between occidental and oriental pears, revealing separate evolution processes. Population structure analysis with K values of 2–8 reflected a clear genetic composition within different genotypes, supporting *Pyrus sinkiangensis* as a hybrid of oriental and occidental pears, and *P. pyrifolia* and *P. bretschneideri* sharing a common ancestor. The comprehensive evaluation of a wide range of pear cultivars by SSR markers demonstrated their excellent application for the study of their genetic diversity and genetic relationships.

Hokanson et al. (2001) studied 142 *Malus* accessions with eight SSR primers and observed a high level of variation. Gross et al. (2014) studied the genetic diversity in apple (*Malus* × *domestica*) and found 96% genetic diversity by using SSR markers. There was no significant difference reported in heterozygosity (*He*) for *M.* × *domestica* compared with *M. sieversii* and *M. orientalis*. The improvement of genetic linkage maps using transferable markers, microsatellites, and RFLPs has provided a base for fruit genetics and breeding. Marker-assisted selection and comparative mapping was done in fruit crops of the Rosaceae family by Dirlewanger et al. (2004). About 13 maps were constructed from 562 markers that helped in comparing genomes among seven species of *Prunus* that included peach, cherry, apricot, almond, *P. davidiana*, *P. ferganensis*, and *P. cerasifera*.

Khoramdel et al. (2013) screened 40 quince genotypes that originated from six distinct geographic areas using 15 SSR markers. They reported 5.36 alleles per locus, with a mean PIC value of 0.76. An unweighted pair group method with arithmetic mean (UPGMA) and principal coordinate analysis divided the quince genotypes into five major clusters. They found that 83% of individuals in the clusters were positioned in their place of origin and concluded that geographic isolation leads to considerable genetic differentiation among Iranian quince collections.

Sharma et al. (2015) analyzed 24 sweet and wild cherry genotypes collected from the Czech Republic to determine genetic variation using 16 SSR primers. All the SSRs were found to be polymorphic and they generated a total number of 70 alleles with a mean of 4.4 alleles per primer combination. The allele frequency varied from 2.1 to 87.5% and the observed heterozygosity ranged from 0.25 to 0.96, with an average of 0.72, while the expected heterozygosity values varied from 0.22 to 0.75, with an average of 0.59. The PIC value ranged from 0.21 to 0.71, with a mean value of 0.523. Cluster analysis separated the cherry genotypes into two groups. The high level of genetic diversity obtained in the collection proved to be genetically diverse and, therefore, these genotypes would be useful to breeders for the development of new cultivars.

Ahmed et al. (2012) analyzed 82 walnut genotypes collected from the North Western Himalayan region of Jammu and Kashmir, India by a combination of 13 SSR and 20 RAPD primers. They observed a high level of genetic diversity within populations, and the number of alleles per locus ranged from 1 to 5 in the case of SSR and 2 to 6 in the case of RAPD primers. The clustering pattern of the dendrogram showed that all the accessions divided into four main clusters with various degree of subclustering within the clusters. These results have very good implications for walnut breeding and conservation programs.

Biotechnological Aspects of Temperate Fruits

Plant biotechnology is an interdisciplinary science that provides solutions to many agricultural challenges by the rapid selection and propagation of elite cultivars, conservation and maintenance of valuable germplasm, molecular-assisted selection, genetic improvement, and safeguarding human health. Such a type of biotechnology allows researchers to detect and map genes, discover their functions, select specific genes in breeding, and transfer genes for specific traits into plants for the development of agriculture and the purpose of improving food quality and nutritional value (Laimer et al. 2005). The implication of plant biotechnology in temperate fruit trees is very helpful for agriculture, health, and mankind by taking part in many areas of research that include:

- Maintaining postharvest biology and technology of fruits
- Identification and introduction of useful traits and genes that can contribute to national and global goals for agriculture

Maintaining Postharvest Biology and Technology of Fruits

The primary goal of biotechnology on postharvest biology and technology of fresh fruits is to reduce their losses in quantity and quality from harvest to consumption. Thus, biotechnology can be a useful tool for addressing some of the issues related to quality attributes and biological deterioration. Biotechnology can be used to improve color uniformity and intensity and to minimize undesirable colors, such as browning. Efforts have been directed to produce genotypes with low browning potential by lowering phenolic content and activities of phenylalanine ammonia-lyase and polyphenol oxidase. Fruit softening was reduced to maintain firmness by altering the cell wall metabolism in fruits and ethylene biosynthesis. Transgenic tomatoes with blocked ethylene biosynthesis have been developed and tested on a commercial scale. The flavor and nutritional quality of fruits was maintained and improved by the manipulation of multiple genes. Isolation of the polygalacturonase gene, antisense construction, and gene transfer has provided useful insights into the role of polygalacturonase in tomato fruit softening (Giovannoni et al. 1989). Gene expression during peach fruit development and softening is being studied with the objective of manipulating softening through gene transfer (Callahan et al. 1991). Genotypic differences in susceptibility to chilling injury have been shown in most chilling-sensitive commodities. Thus, it is possible to produce cultivars with lower chilling sensitivity to allow their handling at lower temperatures, especially in the winter season, for extending their postharvest life (Kader 2000).

Identification and Introduction of Useful Traits and Genes

Genetic transformation is a technique of altering the phenotype of fruit trees by adding single horticultural traits in existing cultivars without changing their commercial characteristics. Genetic improvement of fruit trees is essential for increasing fruit production. For most of these species, the desired new varieties contemplate the presence of agronomic and horticultural traits related to propagation, yield, appearance, quality, disease, pest control, abiotic stress, and shelf life. Incorporation of these traits into the genetic backgrounds of species by conventional breeding needs overcome some major disadvantages, such as long generation time, complex reproductive biology, high levels of heterozygosity, limited genetic sources, and linkage drag of undesirable traits from wild relatives. In addition, breeding by controlled crosses is hampered due to factors specifically related to complex characteristics, such as delayed flowering, unsuccessful fruit setting due to abortive embryos, massive fruit drop, and self-incompatibility barriers. Although the use of new technologies based on high-throughput platforms for sequencing and genotyping has deeply contributed to accelerating the association of molecular markers and major genes to their relevant traits, the feasibility of genetic modification relies on adequate technical systems which allow for results to be obtained in a reasonable time

frame. Regardless of the transformed events, highly regenerative systems for explant production and whole-plant regeneration are key steps in fruit tree genetic transformation (Prieto 2011).

Different traits have been modified in transgenic fruit trees, which comprise: (a) altered processing and storage qualities, (b) modified nutritional properties, i.e., the effect of desirable and undesirable components, (c) modified growth habit and vigor, (d) resistance to abiotic stresses, e.g., drought, low temperature, soil factors, and (e) resistance to biotic stresses (Laimer 2003). The breeding and cultivation of virus-resistant plants is a major contribution for the control of viral diseases. Work on pathogen-mediated resistance focusing on virus resistance breeding in fruit trees started in 1988 at the Institute of Applied Microbiology (IAM). For explaining the pathogen-mediated protection approach, the coat protein gene of the stone fruit pathogen plum pox potyvirus (PPV) was isolated and transformed in different explants, i.e., cotyledons, leaf disks, and embryogeneic callus cultures, of different *Prunus* species (Baulcombe 1996; Waterhouse et al. 2001). Several transgenic lines were then regenerated and subjected to genetic characterization and evaluation of pathogen protection. Additionally, sequences of the PPV genome involving structural and non structural genes were introduced in different plasmids in both sense and antisense orientations for transformation and showed good levels of resistance in herbaceous model plants (Korte et al. 1995).

Embryogenic transformation lines of 14 different grapevine cultivars and rootstocks have been established that reported enhanced resistance to nematodes (Gölles et al. 2000). Currently at the IAM, many different fruit trees have been transformed, such as apricot, plum, cherry, and grapevine lines, with different sequences of the PPV genome, the *Prunus* necrotic ringspot virus genome, the genome of different grape viruses, e.g., grapevine fanleaf virus (GFLV), arabis mosaic virus (ArMV), grapevine virus A (GVA), and grapevine virus B (GVB), together with different marker genes, e.g., GUS, GFP, or NPTII (Korte et al. 1995; Gribaudo et al. 2003). These plants represent valuable tools to improve our understanding of host–pathogen interactions and may possibly allow the development of alternative defense strategies for crop plants (Laimer 2005). Efforts are required to create public understanding and acceptance for these crop plants. To build public confidence, many projects were initiated to demonstrate the step-by-step principle of working with genetically modified organisms (GMOs) in the case of transgenic fruit trees.

The damage and losses caused by fruit pathogens are unacceptable to orchardists, marketers, and consumers. For the last 20 years, genetic transformation of fruit crops has focused on enhancing disease resistance (viruses, fungi, and bacteria), increasing tolerance of abiotic stresses (drought, frost, and salt), and many agronomic and horticulturally important traits, such as improved fruit quality, long shelf storage life of fruit, and fruit softening and ripening (Litz and Padilla 2012). However, the development of genetically modified fruit plants and their commercialization are hindered by many regulatory and social hurdles. From the biosafety and consumer points of view, the presence of selectable marker genes, which are essential for the initial selection of transgenic plants, is undesirable in the latter stages (Tuteja et al. 2012). Therefore, the production of ‘clean’ marker-free

transgenic fruit plants is now an essential requisite for their commercial exploitation (Gambino and Gribaudo 2012; Rai and Shekhawat 2013). Genome-wide genetic maps became important for the identification and isolation of genes and study of their structure, expression, and function. These maps allowed the mapping of genes associated with many agronomical characteristics of interest, such as dwarfing, fruit acidity, apomixes, male sterility, resistance to salinity, and disease resistance. The integration of transcriptomics and metabolomics could also generate more accurate information about the biochemistry and physiology of fruit plants, such as transcription, translation, environmental effects, and metabolite accumulation (Machado et al. 2011).

Conclusion

Temperature, light, rainfall, humidity, frost, fertilizers, and soil requirements affect the growth and production of temperate crops. The high biodiversity in morphological, biochemical, and genetic terms revealed a diverse origin of temperate fruits that have an imperative role in preserving germplasm for future use in breeding programs. The increase of desirable genes in the breeding stock is a step-by-step process in which the choice of parents is only one step. Since genetic uniformity is a threat to the improvement of breeding families, a wide genetic base is necessary to avoid an increase in inbreeding levels. The implication of plant biotechnology in temperate fruit trees allows researchers to detect and map genes, identify their functions, and transfer specific genes into plants for the development of agriculture, health, and mankind.

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Orchard Management in Temperate Fruits

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Introduction

Orchard management is arguably an important aspect for the cultivation of fruit crops and it should be planned before the establishment of an orchard and executed in a timely fashion for bringing about earliness and maximum quality return. Orchard management represents a substantial portion of the orchard agroecosystem but it is a matter of regret that it has not attained as much importance as other horticulture and pest management practices. The primary objective of an orchard management program is to provide conditions that favor the development of healthy trees capable of providing high return of quality fruit. Attention must be given to the prevention of extreme conditions, such as deficiency or toxic effects, that could seriously impair tree performance in any season or throughout the orchard's life. Existing knowledge from diverse growing regions needs to be examined for widely applicable practices, as well as practices best suited to a more local set of conditions. It is, therefore, important to analyze all the components of the orchard system to determine where adjustment might result in desirable improvements. This review chapter focuses on fruit crops experience and attempts to identify key considerations for orchard management and suggest priority information or knowledge for future research, in order to determine opportunities for increasing and sustainable productivity.

Orchard management requires proper planning right from the purchasing of land and planting of nursery plants, through to the tending of the crop, and then harvesting and selling of the produce. An orchard is a long-term investment and its careful planning and resource analysis prior to establishment is essential. Lack of attention and care in the initial stages of orchard development results in irreversible damage. Essential resources for successful orcharding can be mainly grouped into two

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categories, biophysical and socio-economical. Biophysical resources include land, soil, agrochemicals, planting materials, irrigation, and manpower, while socio-economic factors include finance, technical knowledge, security, transport, storage, marketing, and social amenities. The selection of crops and varieties should be done carefully.

Orchard management first starts from the soil selection process, i.e., it must be tested for nutrients, and, subsequently, there is a need for a specific plan for what kind and variety of crop is to be planted there. This involves the technical knowledge of what kind and variety of crop will grow successfully there, keeping in mind at the same time supply and demand. The second phase of orchard management is its subsequent care. This includes proper nourishment and to safeguard the crop against natural hazards. After that, the crop needs special training and pruning practices to set a desired shape. However, side by side, great attention should also focus on other important factors like irrigation and weed management. The lack of any one of these management practices will directly or indirectly affect the growth of the fruit plant and, ultimately, the yield.

Careful management of an 'orchard' is essential for successful fruit growing. Further, optimum expenditure and efficient management becomes necessary to keep an orchard running for profit. These are the factors which cannot be overlooked when it is planned to set up the orchard and, evidently, these should be attended by a realistic approach rather than from a theoretical point of view. Therefore, standard orchard management practices should be followed in orchards in a timely fashion to ensure optimum productivity and high quality fruit.

Keeping these points in consideration, orchard management can be broadly classified into the following aspects:

1. Soil management
2. Nutrition
3. Training and pruning
4. Irrigation
5. Weeding

Soil Management

Soil management refers to the management of an orchard's soil in such a way as to obtain higher yields of good quality fruit over a period of years. Prior to and after planting, soil management should include such practices which would tend to increase organic matter in the soil rather than to deplete it. Such practices should be adopted which would tend to discourage the development of soil organisms that would be harmful to the fruit crop. For example, soil in which peaches are to be planted should not have/had crops which are susceptible to nematodes in the years immediately preceding the planting of the crop. Crops which are susceptible to nematodes tend to favor a buildup of these organisms, which are harmful to peaches.

As a result, peach trees will be injured unless the soil is fumigated to reduce the nematode population.

Another prerequisite of soil management prior to planting is the development of the area so that the land is relatively leveled. It is important to eliminate low wet spots or areas which are in poor physical condition. Any good soil management program should aim for the conservation of moisture and useful microorganisms. It should favor the availability of nutrients and ensure proper aeration and buildup of organic matter and maintenance of an ideal pH level.

The management program should be inexpensive and the choice of management system depends on the altitude, kind of fruit, rooting depth of trees, topography, rainfall, climatic conditions, particularly temperature and rainfall, and, finally, the economic conditions of the soil management. Gras and Trocme (1977) concluded that soil management effects were greater than those of N, P, and K fertilizers. The different types of soil management practices/systems are given in the following sections.

Clean Cultivation

In this system, the soil under trees is kept free from grasses or any other vegetation. This system involves continuous weeding, which can be achieved by manual labor and use of herbicides. Mechanical cultivation cannot be carried out on slopy lands or narrow terraces. The root system of such a fruit tree plantation is weak, shallow, and, thus, they obtain most of the nutrition from near the soil surface. Therefore, the clean cultivation system is especially important during the growth of young trees. Weeds in orchards have well-established roots and take the bulk of the moisture and nutrients from the soil, which results in greater setback to the growth of young trees. The competition of such factors can only be reduced by clean cultivation. Thus, clean cultivation tends to increase nutrient availability, especially if it keeps the soil well aerated and reduces weed competition. These are the factors which favor growth of the fruit plants.

However, soil erosion is often a serious problem when clean cultivation is used. The continued cultivation of soil over a number of years without adding organic matter to the soil usually results in deterioration of the soil in fertility and its physical characteristics. A soil which has been cultivated over a long period of time will have lost much of its structure, it will be poorly aerated, and nutrients will not be readily available. Soil with poor structure will not make much water available to the plants and will have greater runoff during heavy rains. The loss of precious top soil along with plant nutrients not only reduces the fertility of the soil, but also affects the performance of the trees. It also causes reduction in population and activity of earthworms and useful microorganisms. It has been proved, through various research trials, that clean cultivation for longer periods is detrimental to trees as well as to the soil. It is, therefore, only recommended for young prebearing trees and should not be practiced during the rainy season.

Sod Culture and Sod Mulch

Maintaining a permanent cover of grass in interspaces is referred to as sod culture. This practice helps in reducing soil erosion especially on slopy areas, but competes with crops for moisture and nutrients, which demands additional manuring and irrigation in such orchards. If grass is cut frequently and spread on the ground, the system is called sod mulch. There is much less damage to the fallen fruits. The system is especially suitable for apple, pear, plum, and cherry orchards. However, no tillering under sod mulch is practiced but sometimes soil is loosened with a rake in the spring. This improves the aeration and water intake capacity of soil.

Successful maintenance of permanent sod in stone and pome fruit orchards can be difficult due to shading of the sod species during the fruit growing season. Large trees of apple, pear, plum, etc. and high-density orchards are particularly restrictive to permanent sod culture. Low growth of the sod species during the summer months is advantageous, as it means that the sod is less competitive with the main crop for water and nutrients, but it must be able to rejuvenate quickly in the autumn. The key to good sod management is frequent cutting or moving of cover crop. It should be moved over after a month during May and June and twice a month during monsoons, when growth is very fast. Increased phosphorus in apple trees with grass has been reported by Perring (1975), who found that trees with grass increase their fruit phosphorus concentration compared with those under cultivation, if supplied with phosphate as a fertilizer.

The major disadvantage of sod culture is that, during drought, there is severe competition against fruit trees for moisture and nutrients. A heavy sod or grassing for years compete with trees for nitrogen, whereas cultivation damages tree roots on surface horizons and reduce the uptake of phosphorus and potassium (Coker 1959).

Before establishing a permanent sod, the soil structure and organic matter levels should be adequate. Sod root systems will aid in developing soil structure and permeability, as well as adding organic matter, but this is a slow process. Sod culture can be useful for loamy soils but in steep areas, it may not be of much use. Sods are better than weeds and wild grasses because they do not take much time to establish and their roots do not penetrate deeply.

Many studies have reported significant yield reduction of apple, pear, and peach under sod management, accompanied with reduced growth and leaf nitrogen concentration (Raese 1977). Both the number and size of fruits have been affected in the short term, with long-term yield reduced because of smaller trees. Dwarfing apple rootstocks (M-9 and M-26) have also been sensitive to yield reduction (Neilson and Hogue 1985). Even with nitrogen fertilization, bloom development may be poorer for trees competing with sod (Neilson and Hogue 1985), with the result that yield efficiencies (expressed as kgs harvested fruit per cm^2 trunk area) are reduced (Miller 1983).

Intercropping

Intercrops are generally deemed to be crops raised in an orchard for increasing the initial income from the land/orchard. These intercrops may be vegetables, pulses, or short-duration fruit crops (fillers). However, intercropping should not be practiced in high-density orchards. Growing intercrops not only earns an income for the grower, but also helps in soil management by reducing weed growth, checking for erosion, and enriching soil. The selection of crops for intercropping should be based on suitability and marketability. For raising intercrops in an orchard, the orchardist must apply additional inputs like fertilizers, irrigation, etc., so that the fertility of the soil is maintained properly for sustainable production in the years to come.

The selection of intercrops depends on the kind of fruit plant, location, type of soil, amount and distribution of rainfall, irrigation facilities, availability of labor, transport facilities, and the availability of packaging material.

Intercrops that create or increase insect and disease problems should be avoided. The most suitable intercrops are leguminous crops like pea, soybean and dwarf bean, cowpea, lentil, and other pulse crops, which have the added advantage of nitrogen fixation in soil. Nowadays, rhizome cultures are available for all these leguminous crops, which increase their nitrogen fixing capability. Strawberries and some vegetables can also be grown as an intercrop, but additional fertilizers should be applied to meet their nutrient requirements.

Cover Crops

These crops are raised mainly in the beginning or in advance of the rainy season, so that these may provide the necessary protection to the soil surface as cover. Cover crops are usually cut and mulched or mixed into soil. In addition to preventing soil erosion, it would mean that the increased amount of growth would result in more organic matter being incorporated in the soil. The soil cover keeps soil warm in winter and cool in summer. Diest et al. (1973) showed that root growth of cover crops could promote the movement of phosphate to deeper soil horizons, which could be utilized by fruit trees. It should always be kept in mind that cover crops utilize moisture and nutrients, and one should plan a cover crop program for both fruit plant development and soil conservation. If soil and topography are such that erosion is not a major problem, the cultivation plus cover crop system is a good method of soil management for fruit crops.

There are a few points to be considered when selecting a cover crop. The two principle types available are legumes and non-legumes. A leguminous cover crop can incorporate considerable quantities of nitrogen in the soil, thereby reducing the amount of nitrogen which needs to be added in the form of fertilizers. This is a distinct advantage for the legumes. However, a cover crop like soybean may aid the buildup of a high nematode population in the soil, which could injure plantations

like peaches. This should always be avoided. Some fruit plants are particularly susceptible to certain soil pests, such as nematodes or certain fungi, which may cause root rot and death of a fruit plant. Cover crops like crotalaria are not also favorable, owing to the buildup of the nematode population. In areas where nematodes are not a problem, cover crops like soybean are quite satisfactory.

Living cover crops have greater weed suppression capacity than dead ones, but they can be quite competitive with crops and, thus, are probably best used in orchards, vineyards, and some other horticultural crops (Sarrantonio and Gallandt 2003). Weed germination and emergence can be markedly reduced by living cover crops and their residues. By using cover crops, seeds of many weeds may be effectively controlled by suppressing light, temperature, and moisture (Teasdale 1993; Sarrantonio and Gallandt 2003).

On sandy soils in particular, the addition of organic matter improves the ability of soil to hold water, especially near the surface. On heavy clay or compact soils, the root activity of the cover crop and the availability of organic matter by cover crop can break up the compact soils and improve the infiltration of irrigation water. Since the soil structure improves, the roots are able to explore more of the soil for water and nutrients. This results in improved tree health, vigor, and yields. The other benefits from cover crops are to increase the earthworm population and their activity, as well as reduce the dust, etc. from the orchard.

Mulching

Mulching is a practice of covering the surface of soil around the plants to make conditions more favorable for growth and to conserve the available soil moisture. The materials used depends upon the availability and economy. Usually, organic materials are spread, but even inorganic materials can also be applied. The mulching material is used primarily with the focus of modifying the impact of the particular climate, as well as keeping the plants/vegetables in a healthy position. Apart from that, the use of mulches also reduces the time spent on different cultural practices in the orchard/garden. Nowadays, different organic mulch materials, viz., paddy straw, sugarcane trash, rice husk, leaf litter, dry grasses, etc., and inorganic synthetic materials like polyethylene sheets may be used in fruit crops.

Better moisture conservation and higher soil temperature with the use of black polyethylene mulch have been observed compared to other mulches of intemperate horticultural crops. Black polyethylene mulch was found to have a significantly better effect on the extent of fruit set and yield in strawberry compared to the other mulching materials tested (Abbotty and Gough 1992; Sharma 2009). The waste materials from various nut processing industries have been used as a mulching material. Walnut hulls and almond shells without hulls have been used as mulch in many prune orchards in the USA. Partially decomposed walnut hulls in a layer 7.5 cm deep were somewhat less effective than almond shells as a weed control mulch, but contain 5% nitrogen, which may act as a fertilizer. The hulls of walnut

may also contain juglone, which is known to be a plant inhibitor (Heath and Krueger 2000). Clear polyethylene was found to be the best in terms of different physical, chemical, and yield attributes, followed by black polyethylene and pine needles in strawberry (Kumar et al. 2012).

Nutrition

As in any other crops, the growth, development, and productivity of fruit plants are also highly influenced by nutrient supply. Fruit crops need more nutrition than field crops. In India however, the fertilization of orchards is faulty and incomplete. Nutrition management of fruit crops is the most important aspect in orcharding for which the productivity of the fruits can be increased. Research trials are needed to formulate the schemes of fertilization which shall prove profitable outcomes for a fruit orchardist under the climatic conditions prevailing at that location.

Nutrients taken up by the plants from the soil are called mineral nutrients. These are derived from minerals. The process of absorption, translocation, and assimilation of nutrients by the plants is known as mineral nutrition.

According to Hewitt (1963), three criteria of essentiality are:

(a) The element must be essential for normal growth and reproduction, which does not proceed in its absence
(b) The requirement for the element must be specific and not replaceable by another element
(c) The requirement must be direct, not a manifestation of indirect effects, such as antagonism of a toxic effect

The number of nutrients obtained from soil is over four times the number of nutrients obtained from air and water. The chief sources of nutrients of plants is soil. In ordinary conditions of agriculture, except drought, carbon, oxygen, and hydrogen are not limited for plant growth. Carbon and moisture (oxygen and hydrogen) constitute about 95% or more of the weight of the plant. It is the remaining group of 13 nutrients from the soil that usually limits plant development and, hence, considerable emphasis should be placed on the improvement of soil in respect of the greater availability of these nutrient elements.

Specific functions are performed by various nutrient elements in all metabolic activities as well as the growth, development, productivity, and quality of plants and their products. The lack of availability in sufficient quantities of nutrients causes deficiency symptoms expressed in different ways, depending on specific roles played by the elements. On the other hand, an excess supply of nutrients results in toxicity symptoms, which may affect growth and development, and may lead to mortality, depending on the intensity.

Most fruit orchards need some fertilizers, lime, or trace element to achieve and maintain optimum tree growth and production. Even very fertile soil, which may need little extra nutrients for years, eventually develop nutrient problems. Deficiency

of boron can be seen on fruits, including traits such as small, flattened, or misshapen fruits, drought spot, internal cork, cracking and russet in apple, premature ripening, increased fruit drop, and low seed content (Brown and Hu 1996). The capacity of boric acid and borate to react with hydroxyl groups is considered the key for understanding boron functions (Bolaños et al. 2004), and research is now focused on the discovery of B complexes in biological systems. The B deficiency symptoms on the roots include reduced growth with brown discoloration of the root tips (Pilbeam and Morley 2007). A recent study indicated that at least three B-binding membrane glycoproteins were detected in the B-deficient plant tissues, indicating that B and certain membrane glycoproteins are involved in the membrane processes associated with cell growth (Redondo Nieto et al.2007). A liquid formulation containing urea, ammonium nitrate, and zinc nitrate (15% N and 5% Zn), patented as NZN, is considered to be particularly effective as a foliar fertilizer, especially for horticultural tree crops (Storey 2007). In India, it has been found that the efficiency of Zn fertilizer use can be greatly improved when it is applied to soil mixed with livestock manure. In freely draining, coarse-textured soils, $ZnSO_4$ is more effective than the less soluble forms of zinc, such as zinc carbonate, zinc oxide, etc., but they were closely comparable in fine-textured, zinc-retaining soils (Singh 2008). Boron was reported to complex with the cell wall and many of its constituents (Ahmad et al. 2009). Swiatkiewicz and Blaszczyk (2009) studied the effect of early (0.4%) and late spraying (0.8%) with $Ca(NO_3)_2$ on the storability and calcium content in 5-year-old apple tree cv. Elise. Foliar spraying with calcium before harvesting significantly increased the Ca concentration in apples in both of the years under study. Fruits harvested with $Ca(NO_3)_2$ had higher flesh firmness and titratable acidity than the control. The use of 0.8% $Ca(NO_3)_2$ before harvest reduces the percentage of physiological disorders and fungal diseases. However, Miwa and Fujiwara (2010) identified the first boron carrier and concluded that plants sense internal and external B conditions and regulate B transport by modulating the expression and/or accumulation of these transporters. The application of 25% nitrogen through subabul plus 75% nitrogen in the form of urea augmented with biofertilizer (*Azotobacter*) resulted in maximum vegetative, physical, chemical, and yield characters of fruit (Umar et al. 2010).

The nutritional requirements of a crop should be assessed before deciding upon fertilizer and manurial application. The nutrient status of soils can be determined by soil analysis. However, leaf analysis has proved its superiority over other diagnostic methods. In this method, the total leaf nutrient concentration, at specific growth stages, is used as an indicator of plant nutrient status. With leaves being the main site of metabolism in plants, their analysis is the most reliable diagnostic method in almost all plant species. The deficiency symptoms for any element depend primarily on the function of the element and whether or not the element is readily translocated from older leaves to young leaves. Some elements readily move through the phloem from older leaves to younger leaves and then to storage organs, which include N, P, K, Mg, and Cl. Others such as B, Fe, and Ca are immobile and the mobility of Zn, Mg, Cu, S, and Mo is usually intermediate. The deficiency symptoms appear first and are more pronounced in older leaves when the element is mobile, whereas symptoms of immobile elements occur first in younger leaves like calcium and iron (Table 1).

Table 1 Nutrient deficiency symptoms on the foliage of fruit plants, along with the carriers

Element	Deficiency symptoms	Carriers
Nitrogen (N)	Stunted plant. In early stages, pale yellow color of older leaves. In acute conditions, younger leaves also become pale and older leaves start falling	Ammoniacal-N – Ammonium nitrate – Ammonium phosphate – Ammonium sulfate and urea Nitrate-N – Calcium nitrate – Calcium ammonium nitrate and sodium nitrate
Phosphorus (P)	Dwarfing and abnormally dark green plant, leaf erect and usually narrow. In acute cases, purple pigmentation, bronzing on back side of leaf. Blossoming poor, delays in fruit maturity, and poor yield	– Monocalcium phosphate – Dicalcium phosphate
Potassium (K)	Yellowing of tips and margins of older leaves. In acute cases, cupping of leaves, marginal necrosis	– Potassium chloride – Potassium sulfate – Potassium nitrate
Magnesium (Mg)	Chlorosis starting from tips and margins with no dead spots, main vein green. In acute conditions, leaf base necrosis, leaves curling upward, become brittle and easy to detach	– Magnesium sulfate – Calcium magnesium carbonate (dolomite)
Sulfur (S)	Uniform yellowing of young leaves along with veins, stunted growth	– Ammonium sulfate – Calcium sulfate
Calcium (Ca)	Young buds become chlorotic, hooks and die back at tip margins, death of terminal buds. Rest of the plant remains dark green. Fruit exhibit water-soaked lesions at blossom end	– Calcium nitrate – Calcium sulfate
Zinc (Zn)	Interveinal chlorosis of young leaves, shortening of internodes, leaves small and erect(rosette). In acute cases, dieback of twigs, fruits small, pale rind at maturity	– Zinc sulfate – Zinc chloride
Iron (Fe)	Young leaves chlorotic, no spots (lime-induced chlorosis)	– Ferrous chelate – Ferrous sulfate – Ferric nitrate
Manganese (Mn)	Leaf chlorotic, main and small veins green, no marked reduction in leaf size	– Manganese sulfate – Manganese chloride
Copper (Cu)	New leaves wilt, chlorotic then necrotic, shoot tips show dieback in summer, multiple bud formation below the dead growing points, gumming in citrus fruits, fruits become misshapen	– Copper sulfate – Chelated copper
Boron (B)	Young expanding leaves necrotic or distorted, death of growing points. Stems may be rough, cracked, or split along the vascular bundles. Fruits small, hard, cracked, central regions of the fruit corky	– Boric acid – Calcium or magnesium borates
Molybdenum (Mo)	In early symptoms, older leaves chlorotic, resembling nitrogen deficiency symptoms and then necrotic spots, leaving holes in leaves. The later stages develop on young leaves	– Ammonium molybdate

Source: Bal (2008)

Manures and Fertilizers

The application of manures and fertilizers to fruit trees constitutes a very important cultural practice. For successful orcharding, one has to apply manures as well as fertilizers at appropriate doses and at the right time. Orchards are manured by both inorganic fertilizers and organic manures.

Application of Manures and Fertilizers

In order to obtain maximum benefits and to minimize the possibilities of any adverse effects, it is important that fertilizers be applied at appropriate times and in a suitable manner.

Time of Application

In temperate regions of India, where the summer and winter months are well marked, there are different periods of growth and dormancy or rest for fruit trees. From February to May, fruit trees have the highest requirements for nutrients for vegetation, flowering, and fruit setting. The time for applying a full dose of P, a half dose of K, and a third dose of N should be 3 weeks before flowering as a basal dose. The other third dose of N and remaining half dose of K should be applied just 3 weeks after fruit set, and the final third of a dose of nitrogen during June–July. Nitrogen and potassic fertilizers are spread within the canopy area and mixed with the soil up to a depth of 15 cm. However, phosphorus should be placed in the deep root zone. The time of application of micronutrients depends upon the kind of fruit trees and the severity of deficiency (Table 2).

Table 2 Recommended concentrations of salts/compounds for foliar application

Nutrient element	Most commonly used salt/compound	%
Nitrogen	Urea	0.5–1.0
Phosphorus	Potassium dihydrogen orthophosphate	0.25
Potassium	Potassium sulfate or nitrate	0.5–1.0
Calcium	Calcium nitrate	0.25
Magnesium	Magnesium sulfate	1–2
Iron	Ferrous sulfate	0.5
Manganese	Manganese sulfate	0.3
Zinc	Zinc sulfate	0.5
Copper	Copper sulfate	0.3
Boron	Borax, boric acid	0.1

Source: Chadha (2001)

Training and Pruning of Fruit Trees

Training and pruning are essential operations in successful orcharding. There are many methods and styles of training, and each has its limitations. One method seems adapted to one situation and another to another situation. For instance, there is a need to hold a desirable but overly vigorous variety in check. In another method, it may be desirable to facilitate entry of sunlight so as to ensure fruit of high quality. The training of fruit trees should be done in such a manner that sufficient air and light penetrates inside the foliage to facilitate proper coloration and development of fruits. Basically, in horticultural plants, there is a transformation of solar energy into chemical energy by the green foliage via the phytochemical process of photosynthesis. This forms the primary source of energy, which ensures food, fodder, fiber, and fuel; therefore, it needs to be harnessed effectively. In fruiting tree, the fruiting potential is largely governed by its architecture, canopy density, and photosynthetic efficiency (Kallow et al. 2005).

The deciduous fruit trees like apple, pear, peach, plum, almond, apricot, and grapes need annual pruning in order to keep them in proper vigor and for obtaining good fruit yields of superior quality over the years. Pruning admits an abundance of sunlight, which is easily accessible for fruit thinning, picking, and spraying of chemicals. The purpose of pruning at any specific time depends upon the age, kind, vigor, and bearing or non-bearing nature of the fruit plant. The choice of the cultivar/rootstock combination is mainly driven by the economic context, whereas that of the planting system (i.e., tree arrangement, planting density, support system, tree shape, and training and pruning schemes) mainly relies on technical issues. The integration of the different components that lead to a successful apple planting is referred to as the 'orchard systems puzzle' (Barritt 1992; Hoying and Robinson 2000). A direct consequence of this multifactorial design is that one cannot establish a single recipe for orchard success that meets all economic, technical, and environmental conditions (Forshey et al. 1992; Wertheim et al. 2001).

It has frequently been stated that the limiting factor in the productivity of an apple tree is the shade it casts upon itself. Equally important in high-density plantings is the shade of adjacent trees. Intensive studies (Heinicke 1964, 1975) have shown that there are distinct light zones within an apple tree, as shown in Fig. 1. To quote Heinicke, "A layer of fruit and foliage on the outside surface of the tree receives a high proportion of the available light far in excess of tree requirements. A second layer further down has adequate light, and a third layer or core in the center of the tree has insufficient light for the production of quality fruit. The solution to greater productivity lies in eliminating the unproductive area of inadequate light, which will improve the overall efficiency of that area of the orchard occupied by a tree."

The zone that receives less than 30% full sunlight is less fruitful and produces smaller fruits of unsatisfactory color. In the past, the usual solution to this problem was the removal of all the bearing wood in the heavily shaded interior of the tree. This was effective in a way because it did eliminate some inferior fruit, but it did not increase efficiency. In addition, this approach continuously forced the bearing wood upwards and outwards, and encouraged the development of very large trees. At wide

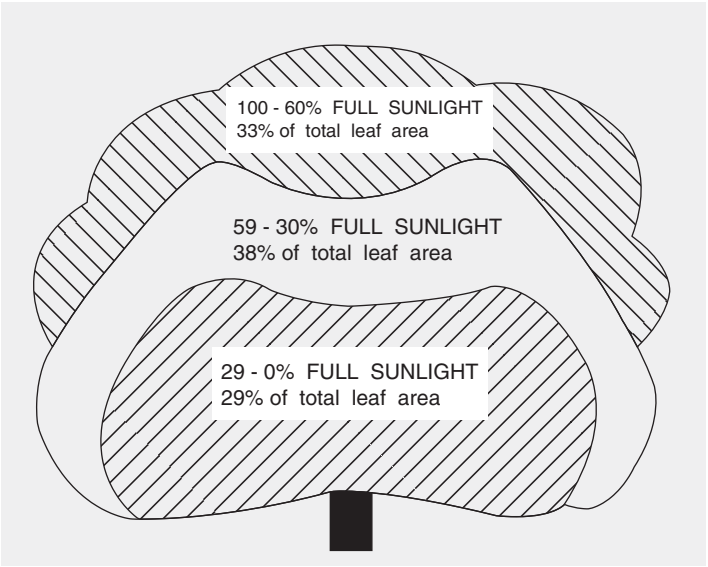

Fig. 1 Light penetration into the canopy of a large apple tree (source: Heinicke 1975, USDA Agriculture Handbook 458)

spacings, this was tolerable, even though it was inefficient. At close spacings, this approach quickly lead to overlapping trees, which heavily shade themselves and each other. This type of open-center pruning can rapidly transform a density planting into an unmanageable thicket. The two most important factors in determining the percentage of the total leaf surface that receives inadequate sunlight are tree size and tree shape.

The possible color and size are the two most important criteria in the market value of apples. For obtaining a good color, fruit must be exposed to a significant amount of direct sunlight in order to obtain a good quality crop. As canopies become denser during the season, summer pruning has become a routine practice in modern apple orchard management systems to improve light penetration to the fruit and control tree size to some extent. Generally, light penetration with good air circulation is important for cherry, peach plum, pear, and apple, particularly red-colored varieties, such as Starkrimson, McIntosh, Early Red One, Red Velox, Gala Red Lum, Super Chief, etc., where the light intensity in the summer is not always ideal for color development. Removing shoots from the outer canopy of dense trees in the summer increases light penetration into the canopy and increases fruit color. However, summer pruning reportedly reduces the final fruit size.

Light relations have been investigated at various levels. At the orchard level, tree shape, distance between trees, and tree height are inextricably connected. Previous studies established some rules, widely adopted currently, to optimize light interception by the whole tree, such as the relationship between tree height and inter-row width, as a function of latitude (Sansavini and Musacchi 1994), the interest of a north–south row orientation at least in temperate regions (Jackson 1980), or the

interest of square—rather than rectangular—planting designs (Wagenmakers 1991; Wertheim 2005).

When a plant is staked or tied or supported over a trellis or pergola in a certain fashion or some of its parts are removed or trimmed with a view to give the plant a definite framework, the operation is called training.

The effect of tree shapes offered by the various training systems have been the basis of modeling approaches relating orchard and tree canopy geometries to light interception. These approaches are mainly based on physical rules without considering subtending physiological characteristics and canopy architecture. In most studies, the tree canopy is still a 'black box': external shape is abstracted as a simple geometrical form (e.g., cylinder, cone) filled with a uniform density of leaf area (turbid medium analogy) (Palmer 1977; Ross 1981; Sinoquet et al. 2007). Model outputs are the total light interception at the orchard scale and light distribution within tree crowns. At the tree scale, isolines of light transmission are computed to analyze either the influence of tree shape (training system) or time in the growing season on the pattern of light distribution within the canopy (Jackson and Palmer 1981; Wertheim 2005). Among the results gained by such approaches, it has been shown that planting density had stronger effects on fruit quality, growth, and light interception than training systems at the same spacing, underlining the plastic response of the tree to canopy manipulation (Hampson et al. 2002). Another result is that light distribution within the canopy is more important than total light interception with regards to fruit quality, irrespective of training systems (Sansavini and Corelli 1992).

Arsov et al. (2013) studied the effect of different training systems on the yield of the Jonagold apple variety and observed statistically significant differences between different training systems. The trees grown under the slender spindle system had the highest yield, whereas the others from the 'V' system had the lowest.

The following training systems are in vogue in different kinds of fruit trees, as shown in Fig. 2.

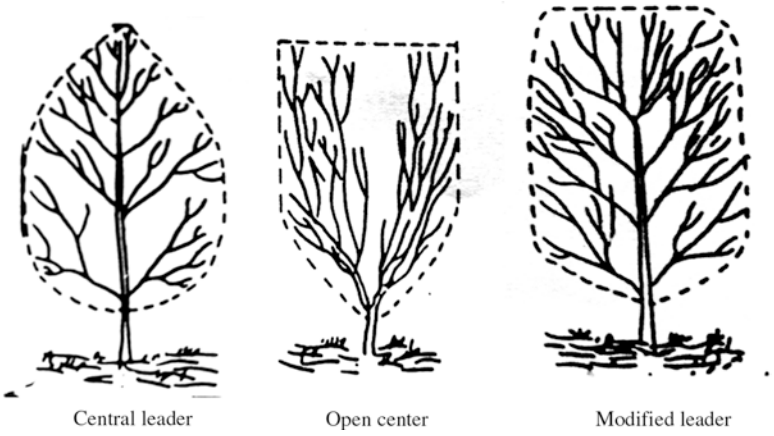

Fig. 2 Major training systems

Central Leader System

In this system, the trunk extends from the bottom to the top. The main trunk is allowed to grow and smaller side branches grow in various directions. It provides a strong trunk with well-spaced and well-distributed branches with strong crotch angles. Shading of the interior part of the tree is the problem which affects the quality of the produce. Such a tree bears fruit more vigorously near the top. The lower branches become ultimately less vigorous and less fruitful. Such trees are structurally best suited to bear load and to resist the damage from strong winds. It is rather difficult to spray, prune, and harvest from trees trained using this system. The system is most suitable for pear, cherry, and pecan.

Open Center System

The main trunk is allowed to grow up to 75 cm by cutting within a year of planting. All side branches are headed back. This system not only needs severe pruning to start with, but also constant efforts to maintain its form through drastic pruning treatment. The system lacks strong crotches and provides a weak framework and, as such, is less satisfactory. The trees so trained allow abundant infiltration of sunlight into the canopy for better coloration of inside fruits. But under subtropical conditions where sunshine is plentiful and there are strong winds during summer, this system is not suitable. However, it may be favored in fruits like peaches, apricots, and plums for admitting more sunlight for better quality.

Modified Leader System

This system combines the best qualities of the central leader and open center systems. It is first trained like the central leader system by allowing stems to grow for the first 2 years, and then headed back at 75 cm height. Then, the central branches are allowed to grow and cut back as in the open system. The laterals are selected to ascend in a spiral fashion up to the central leader and are cut back until the proper number and distribution of branches are obtained. Moderate pruning is required in this system. The trees possess strong crotches and a durable framework. Owing to the limited height of trees, spraying, pruning, and harvesting may be done easily and is suitable for most of the commercial fruit trees, like pear, apple, quince, etc.

Apart from these training systems, fruit trees are grown in a specific form following certain techniques. Such techniques are mainly of two types, with and without the help of supporting structures. Systems with supporting structures include bower/pandal, espalier, kniffin, telephone, and Tatura trellis systems. Head, palmette, spindle bush, dwarf pyramid, and head and spread systems come under techniques without the help of supports.

Many orchard systems have developed over the years to meet special climate, equipment, labor, and market needs at specific locations. Orchard systems developed in fruit districts around the world include the freestanding central leader, vertical axis, slender spindle, super spindle, tall spindle, slender pyramid, Solaxe, Tatura trellis, V-spindle, and HYTEC.

As mentioned, each of these systems are made up of seven building blocks (components). These are the seven pieces of the orchard systems puzzle that must be integrated to achieve a successful orchard. Each orchard system is a unique combination of these factors. For example, the freestanding central leader system is a non-supported medium-density system of pyramid-shaped trees planted in single rows on a semi-vigorous rootstock with a central leader trained vertically up to a height of 4–5 m (13–16 ft). In contrast, the slender spindle system, also a pyramid tree form, is planted at much higher densities, often in multirow arrangements, uses a dwarfing rootstock, is supported, and is trained to a height of approximately 2–3 m. It is often assumed that tree training techniques (pruning and limb positioning) are the major factors contributing to the superior performance of one system over another. For example, it has been suggested that positioning limbs below the horizontal (Solaxe) or training the leader at an angle (Tatura trellis, V-spindle) contributes to improved productivity. As we will see below, tree training may not be as important in terms of orchard productivity as factors such as tree density or rootstock. There have been a number of studies in different countries that have compared the productivity of various orchard systems. In most studies, there have been differences in productivity between orchard systems. However, it has generally not been possible to conclude which of the major factors (components) contributed to improved productivity. It was not possible, for example, to determine if tree density, rootstock, or tree training were the critical factors. The goals of this article are to first help decide which of the orchard systems components makes significant contributions to performance and, second, to select orchard systems components that, when combined, result in an efficient and highly productive orchard system. It has been a common conclusion with orchard systems trials that the most productive systems, on a per-hectare basis, were the systems planted at the highest tree density and that the least productive systems had the lowest tree density.

Fruit size is also closely related to the number of fruits per tree and tree volume. Ultra high density orchards have a negative impact on fruit size. A loss of fruit weight with large-fruited varieties like Jonagold, Mitch Gala, Fuji Zhen Aztec, etc. may be tolerated or may even be an advantage as compared to medium-sized varieties like Royal Gala (Mantinger and Vigel 1999). Intensive super spindle orchards (Weber 2000) in the fertile areas of the Italian Alps with an intra spacing of 0.5–0.7 m between plants achieve good crop yield and quality. The strong curvilinear relationship between tree density and cumulative yield at the end of the year indicates that, although the super spindle system produced the highest yield, the medium-density systems produced almost the same cumulative yield. Weber (2001) found that, although tree density was 3.5 times greater in super spindle than slender spindle, the cumulative yield per hectare of super spindle was only 1.3 times higher than that of slender spindle. It is likely that, as the orchard ages, the relationship will

be even more strongly asymptotic (Robinson 2003). Crassweller and Smith (2004) reported that, in the fourth year, small differences in cumulative yield/ha were observed between slender spindle, HYTEC, and vertical axis. The changing relationship from a linear one during the early years to a curvilinear one at year 7 indicates that the highest density systems have a greater advantage in the early years, but that in the later years, this advantage disappears. The optimum density from an economic perspective is probably somewhat less than the highest density due to the law of diminishing returns (Robinson 2003). High-density plantings in apple production allow greater early productivity, an earlier return on capital investment, and high yields of good quality fruit. Therefore, these systems were widely adopted by American and European fruit growers in the past three decades (Hampson et al. 2004). The very high density systems would have the greatest potential when the orchard lifespan is short or when fruit prices are very high during the early years of an orchard's life. It is a well-known fact that smaller size fruit trees provide better distribution of light in the canopy (Dorigoni et al. 2006; Dorigoni 2008) and earlier yields than a few big trees (Robinson 2007). Similarly, in Turkey, high-density planting systems were used by some apple growers for the past decade and such systems are becoming increasingly widespread in Turkey (Ozkan 2008). The effects of five training systems on tree growth, fruit yield, and some fruit characteristics were assessed in apple cv. Jonagold grafted on M-9 rootstock. The trees were trained in one of five ways: slender spindle (SS; 4761 trees/ha), vertical axis (VA; 2857 trees/ha), HYTEC (HT; 1904 tree/ha), and two different tree densities of super spindle (L-Super S with 5000 trees/ha; H-Super S with 10,000 trees/ha). When cumulative yields (CY)/ha were evaluated, the yield advantage of high-density planting was clearly evident for the first three cropping years. H-Super S systems had the highest CY/ha and achieved a yield of 91.24 t/ha in year 4, in comparison to HYTEC having a yield of 33.46 t/ha. The training systems had no significant effect on the average fruit diameter, weight, firmness, soluble solid, and titratable acidity (Ozkan et al. 2012).

Pruning

Pruning may be defined as the partial or complete removal of vegetative growth of fruiting wood from a plant to control its size, remove broken or damaged tissue, alter plant shape, remove unnecessary growth, or balance fruiting and vegetative growth. Pruning invigorates the plant, prevents overbearing, increases the size of the fruit, and aids in the control of pests.

Pruning is done in late winter when the weather is mild or in early spring before the growth starts. However, summer pruning of fruit trees is also satisfactory for removing vigorous sucker growth and some terminal shoots, thus maintaining a moderate tree size.

Methods of Pruning

Generally, trees are pruned annually in two ways.

Heading Back

Heading is when only one-third to one-half of the terminal portion of the branches having their basal portion intact are removed. Heading cuts stimulate vegetative growth, decrease flowering, and destroy apical dominance of twigs, shoots, or branches. When heading a branch, prune just above a bud pointed in a desirable direction and make a diagonal cut.

Thinning Out

In thinning out, a few twigs, shoots, or branches are completely removed, which induces fruit bud formation in the remaining plant parts. Sometimes this practice is used for the rejuvenation of old orchards.

When removing a branch (thinning out), make the cut close to and parallel with the supporting limb. For proper healing, make the cut just outside the 'collar' (swollen region) at the base of the branch to be removed, but do not leave a stub.

Methods of pruning depend mainly on the nature of trees, predominantly the bearing habit. Plants producing flowers and fruits on the current season's shoots respond positively to regular pruning, whereas those bearing fruits on last season's or old shoots should not be pruned severely, since it leads to reduction in flowering and fruiting shoots. Large pruning wounds should be protected with some covering to exclude rot-causing fungi. Bordeaux/Chaubattia paste is a good covering for wounds having diameter more than 2 cm.

Apart from different training and pruning practices in canopy management, phytohormones also play a greater role in controlling many physiological processes of plants. Watanabe et al. (2008) observed different amounts of phytohormones present in leaves and shoots of apple, depending upon their canopy management. No doubt, tree growth management is mostly controlled by physical measures, viz., dormant and summer pruning. A number of plant bioregulator chemicals have been used to control excessive growth in fruit crops, such as paclobutrazol and prohexadione calcium. Several reports are available dealing primarily with the effect of prohexadione calcium on vegetative and fruit formation (Byers et al. 2004; Rademacher et al. 2004). Soil application of paclobutrazol in apricot trees significantly retarded the shoot growth, tree trunk cross-sectional area (TTCSA), and increased the number of fruits per tree (Mir et al. 2015).

Irrigation

Irrigation forms an essential orchard management criteria in the cultivation of fruit crops. Irrigation charges constitute an important item in the cost of production. Success in gardening depends on how economically and efficiently irrigation practices are adopted. It is the most practical and efficient method for controlling drought. In areas which are dry and drought-prone, irrigation is necessary. The objective of any irrigation system is to provide sufficient water to trees to ensure a balanced growth and to prevent water stress, which will reduce yields to uneconomic levels. Requirements of water by plants differ according to climatic conditions, type of crop, type of soil, cultivation, and management practices (Fig. 3). The quantity of water to be applied and the frequency of irrigation should be standardized for a species under specific agro-climatic conditions. During the establishment stage, watering is inevitable for all fruit crops. Afterwards, the requirements of irrigation depend on the crop nature and critical stages. For example, grapes require high moisture during flowering and berry development, but need little stress during ripening.

Water is used in photosynthesis to form sugars, as a solvent for biochemical reactions, and for the translocation of cell constituents and support of the plant by turgor, but only about 1% of the water absorbed by plants is utilized for these metabolic activities. However, frequent water stress may upset the nutrient status of plants, resulting in various nutrient deficiencies and metabolism during the growth period and cannot be fully recouped, even if heavy rains follow. Therefore, the lack of moisture can increase preharvest drop and fruit drops later in the season after the June drop. Drought is likely to accentuate the problem of alternate bearing in apple trees, thus resulting in lower production.

Water stress reduces several aspects of fruit growth and development. After bloom, fruit set appears to be dependent on the maintenance of an adequate rate of fruit growth. Hence, during early cell division, reduction in fruit growth can lead to reduction in both fruit set and the potential for optimum size of fruit at harvest

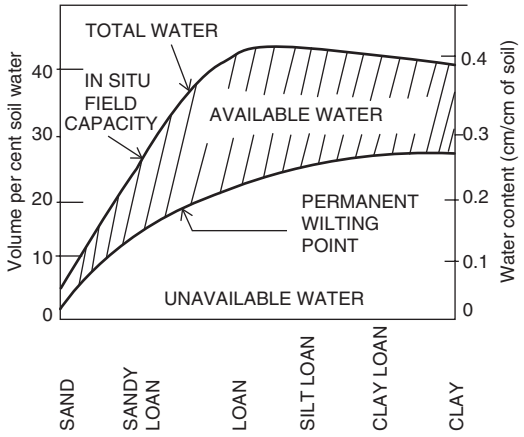

Fig. 3 Available water in different soils (source: Chadha 2001)

(Powell 1974), although, often, these early-season processes are completed before severe stresses develop. Reductions in fruit growth are the most common fruit responses to water stress in apples (Ebel et al. 1993; Kilili et al. 1996; Mills et al. 1996). The reduction in fruit size caused by the stress of water may cause firmness to increase. In some cases, this increase in firmness has been found to be independent of fruit size (Mpelasoka et al. 2000), while in several cases, the increase was not significant when different fruit sizes were compared to each other (Ebel et al. 1993).

In irrigated horticultural production systems, increased precision in the form of water and nutrients can be fulfilled by simultaneous application of fertigation (Bar-Yosef 1999; Neilsen et al. 1999). This application has the benefit of synchronizing nutrient supply with the demands of plants (Millard 1996;Neilsen et al. 2001), thus enabling a reduction in the amount of nutrient application, thereby reducing the environmental impact (Tagliavini et al. 1997; Neilsen and Neilsen 2002). Under drip irrigation, the localized application of fertigated NH_4-based fertilizers reduced the soil pH (Haynes and Swift 1986). Fertigation with ammoniacal N and P fertilizers decreased the pH (Parchomchuk et al. 1993) and increased cation leaching (Neilsen et al. 1995) within 3 years of planting in high-density apple orchards.

Water Requirements of Fruit Trees

The water requirements of fruit trees depend on the growth habit and life period. The water requirements of a plant is the total water required for consumptive use, i.e., for transpiration and for building up plant and fruit tissues, and non-consumption water use. Water is lost by evaporation from soil and foliage and its percolation below the root zone. Water requirements can be understood by the following equation:

$$WR = E + T + B + P$$

WR = Water requirement

E = Evaporation

T = Transpiration

B = Water required for building up of plant body which is small, and

P = Percolation

The amount of water required for irrigation can be worked out by the following equation:

$$IR = WR - (ER + S)$$

where IR is the amount of water required through irrigation, WR is the total water required, ER is the effective rainfall which forms part of the consumptive use, and S is the amount of moisture contributed from the soil profile as stored moisture in the root zone.

The pome fruit trees growing at lower altitudes may require more irrigation. Water requirements may increase in spring when the leaf surface area increases. The maximum water deficit in the leaves usually occurs around 2.00 pm on a clear day, whereas the minimum deficit is around 2.00 am. Considering the prevailing condition in temperate orchards in India, it can be safely assumed that water requirements in apple orchards may be about 10–12 ha cm per month during May and June (1 ha cm is equal to 100,000 L).

Dose and Frequency of Irrigation

The irrigation water to be supplied in terms of dose and frequency depends on a number of factors, like type of fruit crop, nature of the soil, slope of the land, and the prevailing weather conditions. Fruit trees should be provided with deep irrigation at an appreciable interval to favor deeper and wider root growth, and to minimize the cost of the operation, which otherwise may develop goose foot type of roots having poor anchorage and may cost more overall. However, quick-growing fruits having a shallow root system favor frequent light irrigation. Most of the fruit plants have their own peculiarity to endure quantum and intervals of water under a set of agro-climatic conditions. In other words, the plants have the capability to withstand wet or dry conditions. Nowadays, the moisture requirements and favorable moisture tensions for the production of most of the important fruit crops have been worked out. The soil moisture tension of a particular orchard may be identified with the help of a tensiometer and compared with the standard of a particular fruit plant to adjust the dose and frequency of irrigation. There are four irrigation methods which are widely used all over the world. These are flood, furrow, sprinkler, and drip irrigation.

In a survey carried out in apple orchards under sprinkler irrigation, it was found that over 80% of the root system and water extraction were restricted to the upper 50 cm of soil (Levin et al. 1972). The fruit yield was 13% higher and there was 20% more commercial fruits (diameter 6 cm and greater) in the combined treatment of high and low moistures during fruit growth and the rest of the season (Levin et al. 1980). The limitation of this system is that it can increase the possibility of spread of scab disease. Wind can also distort the sprinkler pattern and cause an uneven distribution of water. The rate of water application should not be higher than the basic infiltration rate of soil. It is easy to apply chemical fertilizers through sprinklers but the use of pesticides and herbicides through sprinklers is not recommended.

Drip irrigation is an advanced method of water application, particularly in high-density orchards of pome and stone fruits. It is a system with high water efficiency, particularly for tree crops on hilly slopes. The water is supplied with pressure after

filling it through pipes with attached hoses designed to supply water in drops. These small hoses are placed around the tree in a circular pattern and the percolating water moves downwards and sideways, wetting the root zone. This system requires a regular water supply. The drip or trickle water irrigation system allows the delivery of water to each plant at its root zone through a network of tubing working under low to medium pressure and only the required quantity of water is given daily to avoid water stress to plants.

High cost of operation, damage to pipelines, and infestation of diseases to underground parts of the plants starting from the collar region are the disadvantages of this system. Nowadays, the most economical method of supplying fertilizers to crops, especially fruits/vegetables and ornamentals, is with irrigation. This technique is called 'fertigation'.

Landsberg and Jones (1981) calculated that the soil–plant resistance would increase much more rapidly in drying soil for plants with low root densities, such as apples. Direct evidence is lacking, but Bonany and Camps (1998) found that tree growth and fruit size increased with irrigation rates of up to 150% of crop evapotranspiration (ET). This has also been seen in almonds, grapes, and citrus fruits (Hutmacher et al. 1994; Williams 1996; Parsons et al. 2001). This question deserves more attention to determine its importance and if there are ways to manage the effect for benefit. In arid climates in which trees depend on irrigation for most of the season, root distributions may concentrate in the wetted zone, especially if nutrients are supplied by fertigation (Huguet 1976; Levin et al. 1979, 1980; Bravdo et al. 1992; Neilsen et al. 2000). Although individual roots may slow growth in relation to drying soil, the behavior of the whole root system is probably much more complex, as it responds to variable soil moistures in the field. Several studies have shown that, in arid climates, over time, apple roots tend to concentrate under drip emitters (Crew and Funk 1980; Bravdo et al. 1992; Neilsen et al. 2000). The role of modern molecular biology is potentially exciting but not clear at this time. For example, recent discoveries of aquaporins that affect membrane hydraulic permeability may be important, but the relevance to field water relations of apple trees will need to be determined (Tyerman et al. 1999).The effects of water stress on fruit development appear to be more severe if the stress occurs during the cell-division period compared with during the cell-expansion period. Reductions in growth during cell division are manifested over the remainder of the season, even if water is abundant later. The reduction in fruit size caused by water stress may cause firmness to increase. In some cases, this increase in firmness has been found to be independent of fruit size (Mpelasoka et al. 2000), while in several cases, the increase was not significant when comparable fruit sizes were compared (Lord et al. 1963; Ebel et al. 1993). Deficit irrigation at critical times during crop development has been tested to control vegetative growth without harming fruit development (Chalmers et al. 1981) or to improve apple fruit quality (Mpelasoka et al. 2000). A key point was to identify a stage of development when the fruit were not actively growing or not sensitive to stress, but the shoots were still active. This occurs in stone fruits and grapes, which have a double sigmoid fruit growth pattern with a mid-season lag in fruit growth while shoots are still vigorous.

Saline irrigation of olive trees with 10 dS m^{-1} water did not cause significant changes of shoot length after a 9-year study, but in a single year, differences might arise and no differences were observed in the annual and cumulative yields among the treatments (Melgar et al. 2009). In arid regions, among olive trees irrigated with treated wastewater and with well water, non-significant injuries caused by salts or heavy metals were observed on shoot growth of trees irrigated with treated wastewater. The application of treated wastewater significantly increased the concentrations of N, P, and K in the leaves, whereas heavy metals (Zn and Mn) showed a significant increase only after the second year of irrigation in olive trees (Bedbabis et al. 2010).

Weeding

Weeds are much more than an eyesore. Weeds are plants which grow out of its place, i.e., where they are not wanted. They are often prolific, persistent, interfere in the cultural operations, increase labor costs, and reduce the yield and quality of the produce. Excessive weed growth in orchards affects the growth and development of the main crops. Weed growth needs to be controlled for high quality produce. Orchardists are mostly indifferent towards weeds and allow them to create havoc by growing, spreading, and disseminating their seeds. Weeds act as host plants and, thereby, intensify the problems of diseases, insects, and other pests. The aquatic weeds reduce the efficiency of irrigation and drainage systems by impeding the flow of water. There are many benefits for controlling weeds in orchards, including more rapid tree growth, greater response to fertilizers, increased fruit size and yield, reduced potential for mouse injury, and elimination of competing flowering species during pollination.

It is critical for newly planted trees to achieve maximum growth in the first 2–3 seasons. Young trees are not as capable of competing with weeds for different aspects like light, water, and nutrients as such root systems are small and the canopy cover is low. A weed-free zone of 1–2 m from trees is ideal.

The productivity of orchards can be increased only when all the aspects of crop production technology, including weed management, are adopted. The yield losses of nearly 33% to the tune of Rs. 16.50 billion are due to weeds (Arakeri 1981) and an average of 30% more on tillage operations. Weeds complete their life cycle in a shorter period as compared to fruit crops; thus, their occurrence and reoccurrence competition for light, moisture, water, nutrients, etc. are greater and, thus, causes a reduction in yield. When weeds grow, the bulk of tree roots form in the second and third foot of soil. In areas with poor quality soils, the orchardists should not give the best foot of soil to the weeds.

Before adopting an appropriate method for the effective management of weeds, it is essential to know about the weed seed disposal, mode of propagation, competition, etc. The weed distribution may be broadly classified as preventive and curative or eradication methods. Preventive measures include all such measures through which the introduction of weeds into the crop fields could be avoided, while curative measures include ways for their management and eradication after they have grown

in the orchard. Various methods of weed control alone or in combination have been tested worldwide. Mage (1982) reported that the most vigorous growth and highest yield was recorded in apple trees planted in soil covered with black plastic. Hay mulch was found to increase growth and plant nutrient status in Red Delicious apple trees due to efficient weed control.

For the control of weeds in stone fruit orchards, one should not use phenoxy compounds, i.e., 2,4-D, 2,4,5-T, as those crops are susceptible to these compounds. Similarly, cherry plant is highly susceptible to dalapon. Bhan et al. (1982) reported that effective herbicides were simazine, atrazine, and bromacil at 5 kg a,i/ha each and terbacil at 3 kg a,i/ha. Shrubby weeds like *Rosa moschata* and *Rubus* species which dominate peach orchards can be kept below damage with the application of simazine and atrazine (2.9 kg a,i/ha), terbacil (8.8 kg/ha), and diuron (4.0 kg a,i/ha) as preemergence and paraquat (4.1 kg/ha) and glyphosate (4.32 kg/ha) as postemergence herbicides proved to be best for peach orchards with no phytotoxic effect (Sharma and Bhutani 1988).

The main practice in strawberry for weed control is organic and inorganic mulching. Black polythene proved to be more effective compared to other mulches. Simazine at 1.5 kg a,i/ha effectively controlled the weeds but did not show any significant effect on yield. However, the application of weedicides helped in replacing the costly hoeing operations (Challa 1993).

Application of herbicides in orchards is being widely practiced at present, owing to the beneficial effects associated with this operation. For different fruit crops, specific growing conditions, type of herbicides, dosage, and method of application have been standardized. Weed competition can reduce tree growth and development by about 50%.

There are data in the literature about the different effects of some soil and leaf herbicides on the growth of fruit species used as rootstocks—from the lack of phytotoxicity and ability to produce good quality rootstocks suitable for grafting, to very strong toxicity after applying some active substances contained in herbicides, causing plant death. An inhibiting effect on growth was established after applying napropamide and pendimethalin under sand culture conditions. This could be explained by the mechanism of action of the active substances. It is known that napropamide stops the growth of the susceptible plants and pendimethalin inhibits cell division and elongation in the meristematic tissues of the stem (Tonev 2000).

A tendency was established, similar to that in the yellow plum seedling rootstocks, that the content of chlorophyll and mineral elements increased in the plants having higher values of the biometric characteristics (Rankova 2004). The economic analysis of the chemical control of weeds in fruit nurseries showed that the application of herbicides in the production of yellow plum and peach seedling rootstocks led to 16–36 times higher return on investment and the efficiency coefficient ranged from 14 to 43 times higher compared to hand weeding. Data on the economic effect of applying herbicides in the production of Mahaleb seedling rootstocks were similar—from 12 to 27 times higher return on investment and from 14 to 30 times higher efficiency coefficient in comparison with hand weeding (Manolova and Rankova 2005, 2007). Analogous results or results close to the model experiments with sand culture were obtained for the inhibiting effect or the

lack of visual phytotoxicity of the soil herbicides napropamide, pendimethalin, and terbacil under in vitro conditions in some vegetative rootstocks—GF-677, MM 106, and Wangenheims (*Prunus domestica*) (Rankova et al. 2004, 2006a, b, 2009).

Here, it should be mentioned that weed control in fruit orchards in general and nurseries in particular should be carried out on the basis of a sound knowledge about the response of rootstock species to the applied soil herbicides, looking for the point of intersection of the herbicide rate, so that it is efficient enough against the weeds and selective to the cultural plant. Thus, a good quality planting material for establishing new fruit orchards will be produced and established.

Inadequate level of input application and weak management capacity present a challenge towards attaining production efficiency among small-scale orchardists. The management of the orchard can influence the effectiveness of irrigation, fertility, disease and insect management, floor management, pruning practices, etc. Producing economic yields of high quality fruit requires judicious management of all these factors. Alternative management strategies have the potential to enhance soil and water quality while maintaining or even increasing fruit yields. In addition to other possible benefits associated with increasing soil organic matter, the ability of these soils to provide nitrogen to growing plants is increased. This represents a very important step towards achieving sustainable nitrogen supplies for fruit production. Enhancing microbial activity by increasing the active carbon and nitrogen poles is likely to increase the proportion of beneficial organisms, creating a favorable environment that helps in reducing the problems of diseases organisms and parasites.

Conclusion

In this chapter, we have provided an integrated approach of different aspects, viz., soil, mulching, training and pruning, irrigation, weeding, etc., and field results to provide insights into the factors that ultimately determine the efficacy of orchard management. Our goal was to provide an elaborate measure of what is known and what remains to be discovered toward reaching the goal of optimizing the utilization of modern crop production. The factors that determine the efficacy of canopy management are complex and encompass aspects of different factors, as well as economics and ease of management.

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Nutritional and Health Benefits of Temperate Fruits

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Introduction

Fruits are an essential component of a balanced and healthy diet. In fact, the World Health Organization (WHO 2003) recommends a daily intake of 400 g or five portions of fruits and vegetables a day for nutrition and good health. Low intake of fruits and vegetables is ranked among the top ten selected risk factors for global mortality (WHO 2009). Furthermore, according to the same organization, insufficient intake of fruits and vegetables globally causes about 14% of gastrointestinal cancer deaths, 11% of ischemic heart disease deaths, and about 9% of stroke deaths. Also, an increased intake of fruits and vegetables has been linked to the lowering of cardiovascular disease risk factors, such as obesity, hypertension, and type 2 diabetes mellitus (Boeing et al. 2012). However, an inverse association between fruits and vegetables intake and cardiovascular disease incidents such as stroke and coronary heart disease has also been established (Bazzano et al. 2003; Dauchet et al. 2006; Wang et al. 2014). Today, consumers not only want to know the nutritional compositions of the food they eat, but they are increasingly demanding of food that is both nutritionally and therapeutically beneficial. Without a doubt, fruits do not only provide the human body with vital nutrients and minerals, but they are also endowed with phytochemicals, including the much-needed antioxidants that are well known

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for their therapeutic values. The chemical compositions of fruits vary depending on many factors, including species, environment, pre- as well as postharvest, and storage techniques, as well as processing, among other factors (Vigneault et al. 2012). Also, fruits begin to deteriorate from the point of harvesting until they are consumed. Therefore, the handling of fruits from the point of harvesting, storage, and processing will play a critical role in their chemical compositions at the point of consumption. For example, some nutrients that naturally occur in fruits may be transformed during food processing and their absorption and metabolism increased in the body. Inversely, it has been shown that partial hydrogenation of vegetable oils results in the formation of fatty acids, while protein heat treatment in alkaline environments leads to the formation of lysinoalanine, and both these products are detrimental to health (Sánchez-Moreno et al. 2012).

Therefore, in this chapter, the nutritional and phytochemical compositions, as well as health benefits, of some temperate fruits, including apples, pears, plums, strawberries, and peaches, are reported.

Nutritional Compositions

Fruits are endowed with both macro- and micronutrients, and these include carbohydrates, proteins, fiber, and fats.

Carbohydrates

Carbohydrates are the main component of fruits, representing more than 90% of their dry matter. Besides the 130 g recommended consumption per day, carbohydrates should constitute between 45 and 65% of the total energy consumed per day (IM 2002). The carbohydrate concentrations in some temperate fruits are shown in Table 1. The carbohydrate compositions of traditional and modern apricot cultivars are extensively reported by Roussos et al. (2015). Suni et al. (2000) reported a decrease in sucrose and starch in some stored apple cultivars in comparison with the fresh samples. Specifically, the carbohydrates, including fructose, sucrose, sorbitol, and glucose, ranged between 6.15 and7.16 mg/100 g. Although fructose was the leading sugar, constituting about 57% of the total carbohydrates under study, the 'Cox's Orange Pippin' cultivar showed higher sucrose levels, while sucrose and fructose made up about 46% each of the total carbohydrates. However, contrary to these findings, Veberic et al. (2010) reported that storing 'Jonagold' and 'Golden Delicious' cultivars of *Malus domestica* Borkh. apples did not affect their carbohydrate compositions. Their results indicate that 'Golden Delicious' had higher fructose, glucose, and sucrose levels. Wang and Camp (2000) reported a decrease in the total carbohydrate concentration in 'Earliglow' and 'Kent' strawberry cultivars with increasing day and lowering night temperatures. Glucose, total carbohydrates, and fructose were highest at 18/12 °C, while a further increase in temperature led to the

Table 1 Macronutrient compositions (mg/100 g) of some temperate fruits

	Carbohydrates	Dietary fiber	Proteins	Lipids/ fats	References
Apples	7.63–9.06	60,700–78,200	3120–20,600	157–446	Suni et al. (2000), Figuerola et al. (2005), Sudha et al. (2007)
Strawberry	2521–3843	1100–2300	500	250–300	Wang and Camp (2000), Ramulu and Udayasekhara-Rao (2003), De Souza et al. (2014)
Peaches	1100–8780	4300	600–6180	230–229	Cascales et al. (2005), Ramulu and Udayasekhara-Rao (2003), Laferrière et al. (1991), Ashraf et al. (2011)
Plums	7840–12,700	27,900–2800	1100–3800	200–800	Roussos et al. (2015), Ramulu and Udayasekhara-Rao (2003), Mehta et al. (2014), Esehaghbeygi et al. (2013)
Pears	8290–9630	900–21,300	8810–14,380	339–560	Kaur and Dhillon (2015), Roussos et al. (2015), Mahammad et al. (2010), Hussain et al. (2015)

lowering of these sugars. Their results also indicate that sucrose was highest and lowest at 25/12 and 30/22 °C, respectively. In a study of the carbohydrate compositions of some plum preparations, Dikeman et al. (2004) found plum/prune sugar alcohols, oligosaccharides, and monosaccharides to be higher in the fruit than in the pit, accounting for 2.9–84% of the substrate organic matter. The study of Cascales et al. (2005) reported that the glucose and fructose content decreased (1280–1270 mg/100 g and 1430–1220 mg/100 g, respectively) in response to maturity in peaches (*Prunus persica*) cv. Caterin, although there were no significant differences between the ripe and unripe fruit. Robertson et al. (1991) had earlier reported a decrease in sucrose and an increase in glucose and fructose due to cold storage in cv. Cresthaven peaches. Storing the Japanese pear (*Pyrus pyrifolia* Nakai) cv. Gold Nijisseiki in temperatures between 10 and 15 °C lowered sucrose contents and increased glucose and fructose in comparison with the fruits stored at 0, 4, or 22 °C (Itai et al. 2015). Storing the pear cv. 'Punjab Beauty' for 3–6 days after exposure of the fruits up to 75 days in cold storage produced variable results on total sugar contents but ranged between 8290 and 9630 mg/100 g. Fruits harvested at optimum maturity showed lower physiological weight loss and fruit softening than those harvested at pre- and postoptimum (Kaur and Dhillon 2015).

Dietary Fiber

Dietary fiber/roughage is composed of non-starch polysaccharides and lignin, as well as resistant oligosaccharides and resistant starch (FAO 1998). High-fiber diets have been linked to the reduction, treatment, and prevention of some cardiovascular diseases, and improved gastrointestinal functions, including the

prevention of constipation. The compositions of fiber in some selected stone and pome fruits are presented in Table 1. Studies have reported high dietary fiber content in cv. 'Granny Smith' and 'Royal Gala' apple peels, ranging between 60,700 and 78,200 mg/100 g, respectively (Figuerola et al. 2005). Gorinstein et al. (2001) reported high dietary fiber in persimmon whole fruit and peels as compared to apple whole fruit and peels. Lintas and Cappelloni (1992) reported higher levels of total fiber in 47 Italian commonly consumed dry fruits in comparison with fresh fruits. These authors further reported that stone fruits are characterized by the dominance of insoluble dietary fiber components. Insoluble dietary fiber adds bulk to the stool and facilitates the quick movement of food through the stomach and intestines (Lembo 2016). Soluble dietary fiber, on the other hand, attracts water and turns into a gel, slowing down digestion in the process but helps lower the risk of heart disease (Threapleton et al. 2013). De Souza et al. (2014), however, reported 1310 mg/100 g fiber content in strawberry pulp, although this was lower than the USDA standard of 200 mg/100 g reported for the same fruit. In general, vegetables contain more total dietary fiber than fruits because of their high composition of cellulose. However, the source of the fiber determines its purpose in human physiology.

Proteins

Proteins play an important and critical role as enzymes, in membranes, hormones, as well as transport carriers (DRI 2006). Therefore, the deficiency of this nutrient often results in anemia, edema, stunting, vascular dysfunction, impaired immunity, and physical weakness (Wu 2016). The recommended daily allowance for protein is 0.008 mg/100 g body weight in adults engaged in minimal activity, whereas 0.02 mg/100 g body weight is safe for adults in terms of long-term consumption (Wu 2016). The protein compositions of some temperate fruits are given in Table 1. Some elevated protein compositions ranging between 3120 and 3680 mg/100 g in cv. 'Royal Gala' and 'Granny Smith' apples, respectively, have been reported in pomace or fiber concentrates, indicating a possible source of protein when whole apples are consumed (Figuerola et al. 2005**).** However, Sudha et al. (2007) reported compositions of about 20,600 mg/100 g in apple pomace. In another study, Brazilian strawberry fruits indicated that protein values, among other chemicals, were in agreement with others reported elsewhere in temperate regions (De Souza et al. 2014). These authors reported 500 mg/100 g protein in strawberry fruits, although this was lower than the USDA range of 670 mg/100 g. In general, animal proteins are arguably the best source of protein, since they provide a complete source of protein, with a complete set of all the essential amino acids, while fruit and vegetables lack one or more essential amino acids (Hoffman and Falvo 2004).

Table 2 Amino acid compositions of some temperate fruits

	Amino acids	References
Apples	Glutamic acid, aspartic acid, phosphoserine, isoleucine	Maro et al. (2011), Sugimoto et al. (2011)
Strawberries	Asparagine, glutamine, alanine	Zamorska (2016)
Peaches	Arginine, lysine, alanine, asparagine, serine, glutamic acid, proline	Jia et al. (2000), Moing et al. (1998), Iordănescua et al. (2015)
Plums	Aspartic acid, glutamic acid, isoleucine, alanine	Ogasanović (2007)
Pears	Glutamic acid, valine, proline, aspartic acid, phenylalanine, threonine, serine	Chen et al. (2007), Coimbra et al. (2011), Sun-Hee and Seung-Hee (2016)

Amino Acids

The role of amino acids (AA) as the building blocks of proteins and polypeptides is well known. However, although over 300 exist in nature, reports indicate that only 20 serve the protein building blocks function (Wu 2009). According to the same author, functional AA such as leucine, tryptophan, proline, cysteine, glutamine, and arginine regulate some key metabolic pathways that are essential for immunity, growth, maintenance, and reproduction. Therefore, their role in improving health and nutrition challenges at any stage of life is important. The AA present in some temperate fruits are shown in Table 2. In different strawberry cultivars, viz., 'Pegas', 'Rusanovka', 'Honey', 'Ducat', and 'Polka', Zamorska (2016) found the AA total composition to range between 3297.9 and 5218.9 mg/100 g, with the highest content in 'Ducat'. During the ripening process in the 'Chandler' cultivar, asparagine, glutamine, and alanine free AA reportedly increased, specifically as much as 16.7 mg/100 g for alanine (Perez et al. 1992). However, Zhang et al. (2011) reported that free AA gradually decrease before red-ripening but rapidly increase when overripe. While nitrogen has been reported to positively affect the total AA contents in some cultivars (Ojeda-Real et al. 2009), Keutgen and Pawelzik (2008) showed that salt stress increased essential AA in the 'Korona' and 'Elsanta' cultivars.

In apples (*Malus domestica* Borkh.), glutamic acid, aspartic acid, asparagines, and O-phosphoserine were the major free AA found in the 'Annurca' cultivar, with asparagine recording more than 70 mg/100 g of the AA (Maro et al. 2011). Also, Wu et al. (2007) showed that asparagine was the dominant AA in apples grown in China and cultivar 'Jonagold' recorded the highest AA value. Sugimoto et al. (2011) reported that developmental stage affected the AA compositions in 'Jonagold' apples. In their report, isoleucine increased by more than 20 times and remained high even during senescence, and this increase was associated with BC ester and ethylene increase. However, Babsky et al. (1986) had earlier reported aspartic acid, asparagines, and glutamic acid in some apple juice concentrate. These authors reported a reduction in AA after storage for 111 days from 438.5 to 57.9 mg/100 g, with asparagine and glutamic acid showing the most drastic reductions. In another

study, Feng et al. (2014) reported that fruits harvested from the inner canopy of the tree had higher AA compositions, indicating that light and temperature may have an effect on their compositions.

On the other hand, Fujian plum essential AA compositions ranged between 59.23 and 100.41 mg/100 g, accounting for about 20% of the total AA that were detected (Zhou et al. 2012). In this work, the 'Tianhuang' cultivar recorded 492.84 mg/100 g aspartic acid. In another study of ten plum cultivars, Ogasanović (2007) reported that the mean AA compositions were about 0.4% of the fresh fruit, while aspartic and glutamic acid were the major AA, making up 41.2 and 10.5%, respectively, of the total AA. The study conducted by Komiyama et al. (1978) had earlier revealed that aspartic acid and asparagine were the major AA, but in some plum juice, they comprised 50–70% of the total AA detected. In this study, 'Ooishi Wase' was remarkably rich in isoleucine and alanine, while 'Methley' had elevated alanine concentrations.

In 'Bartolomeu' pears, Coimbra et al. (2011) showed that sun drying fresh pears reduced Pro, Gly, Ala, Asx, Glx, and Val free AA. In this study, sun drying lowered the AA compositions by 49% in the first year and 38% in the second year, indicating that storing has a negative effect on AA compositions in pears. Sun-Hee and Seung-Hee (2016) studied ten pear cultivars in Korea and reported glutamic acid, valine, proline, aspartic acid, phenylalanine, and threonine as the dominant AA. Aspartic and glutamic acid were the most abundant, and these were reported in *P. ussuriensis* var. 'Ingyebae' (5951 mg/100 g) and *P. bretschneideri* var. 'Yali' (1009 mg/100 g), respectively. Serine has been reported as the major AA in pears grown in China, while cultivar 'Dangshan' was reported to contain the highest value of total amino acids (Chen et al. 2007).

In Romanian peaches (*Prunus persica*), arginine, lysine, and alanine were the most dominant AA and alanine, which had the highest value (1330 mg/100 g), was dominant in the HB 4/81 cultivar, while 'Marqueen' and the IFF 853 hybrid had the highest lysine and 'Mariana' the highest alanine (Iordănescua et al. 2015). In Japanese peaches, Jia et al. (2000) showed that asparagine, serine, and arginine increased sweetness, while aspartic acid increased the sourness of peaches, indicating the effect of AA on fruit taste. Moing et al. (1998) reported that asparagine, glutamic acid, and proline were the major AA in peaches. In their study, asparagine was higher in 'Jalousia' and glutamine in 'Fantasia' cultivars; however, 'Jalousia' reported the highest total AA composition. In peaches, high levels of AA have been associated with the early developmental stages, while a decrease that is reported during ripening is associated with organic acid catabolic enzymes and an induction of transcript encoding AA (Lombardo et al. 2011).

Lipids

Lipids are a heterogeneous group of substances found in plant and animal tissues, are relatively insoluble in water and soluble in organic solvents (chloroform and benzene), and are broadly classified as fats, phospholipids, sphingomyelins, waxes,

and sterols (Abdulkadir and Jimoh 2013). They are the richest sources of metabolic energy (ATP) in all classes of nutrients and enhance the taste and acceptability of foods. The FAO/UN (2010) recommends a fat intake range between 20 and 35% of energy, depending on age, physical activity, and nutritional status of the individual, among other factors. The fat compositions of some fruits are shown in Table 1. Özcan and Hacıseferoğulları (2007) reported a total fat composition of 2100 mg/100 g in strawberries. Figuerola et al. (2005) reported 1570 and 4460 mg/100 g in cv. 'Granny Smith' and 'Royal Gala' apple pomace, respectively. The composition of lipids in some strawberry cultivars of Brazilian origin was 250 mg/100 g, and this was lower than 300 mg/100 g that the USDA reported for the same fruit (De Souza et al. 2014). While some cultivars may differ in their lipid compositions, it is generally accepted that a diet providing 1–2% of its calorific energy as fat is suitable for humans. In addition, although some fruits may provide some form of lipids, these cannot replace those from nuts and fish due to their chemical compositions and, therefore, may not be viewed as substitutes.

Minerals

Table 3 shows the mineral compositions of some temperate fruits. The mineral compositions of strawberries have also been reported extensively. In a study of 'Korona' and 'Tufts' varieties, Mahmood et al. (2012) reported a decrease with maturity in Na, P, Ca, Mg, Zn, Fe, Mn, and Al, while K and Cu increased. Zn and Fe drastically decreased from 1165 to 4920 mg/100 g and 1110 to 4680 mg/100 g, respectively, indicating the high volatility of these minerals in strawberries as they reach the point of maturity.

Apples are well known for their mineral compositions, although these vary with different cultivars. In a study carried out on 15 cultivars from Romania, the minerals decreased in the following order: K > Mg > P > Ca > Na > Fe > Zn > Cu > Mn > C r > Sr > Al (Nour et al. 2010). Minerals such as Fe, Mn, Zn, and Cu recorded very low values, whereas Al was below the limit of detection in 12 cultivars. 'Early Red' recorded the highest (mg/100 g) Na (8.92), Mg (11.84), Fe (0.40), and Al (0.06), while 'Florina' recorded the highest (mg/100 g) K (160.85), Ca (8.74), P (17.04), and Cu (0.07). 'Prima', 'Granny Smith', and 'Alert' reported the highest (mg/100 g) Ca (8.74), Mn (0.06), and Zn (0.26), respectively. These results indicate the high mineral compositions of the 'Early Red' and 'Florina' cultivars. However, the study of Delian et al. (2011) reported higher values of Ca (6.15–26.68 mg/100 g) and K (49.25–185.71 mg/100 g) but in 'Irisan' apples. Mg and Fe recorded 8.72–23.69 mg/100 g and 6.29–10.68 mg/100 g, respectively, with the highest values being reported in hybrid 95/15. In other regions, Boudabous et al. (2009) reported lower values in Tunisian apples. The minerals decreased in the order K (0.54–1.40) > Na (0.03–0.18) > P (0.02–0.10) > Mg (0.02–0.06) > Ca (0.02–0.04) > Zn (<0.01) > Fe (<0.01) > Cu (<0.01) > Mn (<0.01) in 'Anna', 'Arbi', 'Chahla', and 'Douce de Djerba' cultivars. 'Arbi' reported the highest (mg/100 g) Mg (0.06), Cu (0.0009),

Table 3 Mineral compositions (mg/100 g) of some temperate fruits

	Mg	Fe	Na	Zn	Ca	Cu	Mn	K	P	References
Apples	0.06–34.8	0.005–2.1	0.18–10.8	0.005–0.90	8.74–48.9	0.0009–0.07	0.007–0.06	1.40–790.1	0.10–17.04	Nour et al. (2010), Manzoor et al. (2012)
Strawberries	100–240	0.12–0.54	1.9–2.9	0.05–0.10	1.0–6.8	0.03–0.14	14.7–46.4	1220–1500	630–720	Recamales et al. (2007), Wold and Opstad (2007), Sarkar et al. (2011)
Peaches	0.61–6.82	0.05–0.48	–	0.05–1.84	0.40–11.31	0.002–0.12	0.02–0.04	18.6–105.2	1.50	Iordănescua et al. (2015), De Melo et al. (2016), Laferrière et al. (1991), Ashraf et al. (2011)
Plums	62–1236.6	12–19.5	–	202.5	78–1968.4	34.64	125	18936.7–21,990	54	Božović et al. (2017), Miloševic and Miloševic (2012)
Pears	0.12–10.06	0.003–0.005	0.02–5.70	–	0.13–14.9	–	0.96	1.12–91.7	1.0–2.92	Kiczorowska and Kiczorowski (2011), Gąstoł and Domagała-Świątkiewicz (2009)

Zn (0.005), Fe (0.005), and Mn (0.0007). 'Douce de Djerba' reported the highest (mg/100 g) Na (0.18), K (1.40), and P (0.10), while 'Chahla' had the highest Ca (0.04) content. These values are far lower than those reported in Romanian apple cultivars. A similar decreasing mineral content order has been reported by other authors, including Manzoor et al. (2012), who reported the decreasing order K > Mg > Ca > Fe > Na > Zn in the 'Kashmiri Ambri', 'Sky Spur', 'Golden Delicious', 'Kala Kullu', and 'Red Delicious' cultivars. 'Golden Delicious' recorded the highest (mg/100 g) K (790.1), Na (10.8), Fe (2.1), and Zn (0.9), whereas 'Red Delicious' reported the highest (mg/100 g) Ca (48.9) and Mg (34.8) contents. The values reported by Manzoor et al. (2012) in Pakistan are higher than those reported by Delian et al. (2011).

Mineral elements in *Prunus persica* have been reported and decreased in the order: K > Mg > Ca > Fe > Zn > Cu > Mn in some Romanian cultivars and hybrids (Iordănescua et al. 2015). This trend is similar to that reported in apple cultivars reported above. K ranged between 97.6 and 105.2 mg/100 g, with the highest value reported in the 'Marqueen' cultivar. Also, Ca and Mg ranged between 9.21–11.31 mg/100 g and 4.64–6.82 mg/100 g, respectively, with the highest values being reported in the 'Yinqing' cultivar. Furthermore, Fe (0.25–0.48 mg/100 g), Ca (0.01–0.04 mg/100 g), Zn (0.16–1.84 mg/100 g), and Mn (0.02–0.04 mg/100 g) were low in the 'July Elberta' cultivar, 9000406 hybrid, 'Piros Magdalena' cultivar, and IFF853 hybrid, respectively. Laferrière et al. (1991) had earlier reported the order Mg (0.612) > Ca (0.395) > Fe (0.045) > Zn (0.005) > Cu (0.002) in some peach fruits. Ashraf et al. (2011) reported that K, Na, Fe, Zn, and Cu had 35, 16, 1.35, 0.69, and 0.12 mg/100 g, respectively, in indigenous peaches of Pakistan. These values indicate variable compositions of minerals in peaches; however, macroelements remain high in comparison with the microelements. Furthermore, De Melo et al. (2016) reported that the addition of organic compost to the soil produced variable effects on the peaches harvested in the first season after application and decreased in the order: K (18.60 mg/100 g) > P (1.50 mg/100 g) Mg > (0.70 mg/100 g) > Ca (0.40 mg/100 g). However, in an earlier study, Rodríguez et al. (1999) showed that minerals in *Prunus persica* decreased in the order Fe > Zn > Cu > Mn. These authors reported that storage of the peaches exerted a minimal effect on the mineral compositions, although some noteworthy effects were detected for Ca, Fe, Mg, and K. Storage had a decreasing effect on these minerals. Also, K was the major mineral in this study, making up about 80% of the total mineral content. K and Fe are, therefore, conceivably the dominant macro- and microelements, respectively, in peaches.

In a study of 'Èacanska lepotica' and 'Èacanska najbolja' plum (*Prunus domestica*) cultivars, P, K, Ca, and Mg were highest in 'Èacanska lepotica' and recorded 54, 151, 78, and 62 mg/100, respectively (Miloševic and Miloševic 2012). In addition, the same cultivar recorded the highest Mn (125 mg/100 g), Cu (34.64 mg/100 g), and Zn (202.5 mg/100 g), while 'Èacanska Lepotica' recorded the highest Fe (195 mg/100 g). Phosphorus and Zn were the dominant macro- and microminerals, respectively. In the Balkan Peninsula, 1400 mg/100 g of K was reported in the 'Prskulja' plum cultivar, while 70 and 60 mg/100 g of Ca and

Mg, respectively, were reported in the 'Bjelica' plum cultivar (Vukojevic et al. 2012). In some cultivars studied in Montenegro (Božović et al. 2017), the minerals decreased in plums as follows: K (18,936.7–21,990 mg/100 g), Ca (770.7–1968.4 mg/100 g), Mg (748.8–1236.6 mg/100 g), and Fe (12–19.5 mg/100 g) in the 'Požegača' cultivar and Zn recorded the lowest values (4.1–7 mg/100 g) in the 'Anna Spath' cultivar. These results further indicate the high amount of K and Fe in these fruits, and these values are within the range reported earlier by Nergiz and Yıldız (1997).

The study of Mahammad et al. (2010) revealed that minerals in the pear (*Pyrus communis*) decreased in the order K > Ca > Mg > Na > P. These minerals were all higher in the pulp in comparison with the peels. The pulp and peels respectively revealed 91.70 and 56.20 mg/100 g for K, 14.9 and 4.20 mg/100 g for Ca, 10.06 and 8.04 mg/100 g for Mg, 5.70 and 2.06 mg/100 g for Na, and 2.92 and 1.00 mg/100 g for phosphorus. Gąstoł and Domagała-Świątkiewicz (2009) proved that foliar application of fertilizers resulted in a significant increase in Ca, K, Mg, and N concentrations in 'Conference' pears and decreased with seasons. However, the highest concentration of minerals was obtained in the peels as opposed to the pulp. The application of Kalcisal + Kalcifos and Kalcisal respectively significantly increased N and Ca, while Sanisal increased the K and Mg concentrations in the pears. The study of Kiczorowska and Kiczorowski (2011) revealed that the minerals decreased in the order K > Mn > Ca > Mg > Na > Fe in both the pulp and peels of some Polish pear cultivars. However, the peels revealed higher, but not significantly so, mineral levels in comparison with the pulp, as follows: K (1.24 and 1.12 mg/100 g), Mn (0.96 and 0.95 mg/100 g), Ca (0.16 and 0.13 mg/100 g), Mg (0.13 and 0.12 mg/100 g), Na (0.02 and 0.02 mg/100 g), and Fe (0.005 and 0.003 mg/100 g). Mg and Mn were highest in 'Concorde', K and Ca highest in 'Conference', Na and Fe in 'General Leclerc', and Fe highest in 'Bonkreta Williamsa' peels. On the other hand, in the pulp, Na, Ca, and Fe were highest in 'Concorde', K and Mg highest in 'Komisówka', and Mn highest in 'Bonkreta Williamsa'. Potassium, which dominated the mineral compositions, is essential for total soluble solids (TSS), aroma, juiciness, size, skin color, and firmness of the fruit.

Phytochemical Compositions

The phytochemical compositions of temperate fruits have been widely reported and are essential for health, as they are able to act as antioxidants that guard against oxidative stress in the tissues. Considering their biosynthetic origins, they can be categorized into alkaloids, carotenoids, phenolics, organosulfur, and nitrogen containing compounds (Bellik et al. 2013) (Table 4). Figure 1 shows a general classification of phytochemicals.

Table 4 Phytochemical compositions (mg/100 g) of some temperate fruits

	Total phenolics (GAE)	Total flavonoids (CE)	Carotenoids	References
Apples	269.76–640.0	0.29–48.6		Marinova et al. (2005), Vieira et al. (2009), Leja et al. (2002), Awad and de Jager (2002)
Strawberries	900–326	4.4–240.4		Ornelas-Paz et al. (2013), Panico et al. (2009), Cordenunsi et al. (2005), Voća et al. (2014)
Peaches	50.9	15.0	2.02–3.96	Marinova et al. (2005)
Plums	1.05–303.6	0.58–136.2		Marinova et al. (2005), Mehta et al. (2014)
Pears	124.7–629.92	38.17–69.9		De Souza et al. (2014), Marinova et al. (2005)

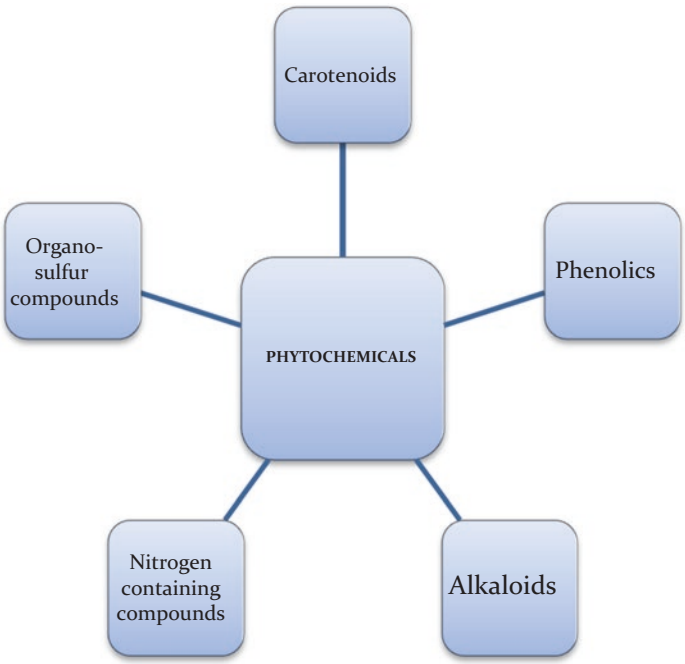

Fig. 1 Classification of phytochemicals

Phenolic Compounds

Phenolic compounds (Fig. 2) are secondary metabolites and play a crucial role in cellular metabolism and physiology. In addition, these compounds determine the taste, color, astringency, and aroma of plants; are responsible for pollination, reproduction, germination, growth, and development processes; and also play a protective role in plants against predators (Harborne 1980; Reis-Giada 2013). The phenolic compounds that are widely known for their antioxidant activity include coumarins, flavonoids, chalcones, phenolic acids, and tannins.

Strawberries are well known for their high flavonol and anthocyanin contents, as well as elevated antioxidant activities by the oxygen radical absorbance capacity assay (Wang et al. 1996). The study by Cordenunsi et al. (2005) showed that anthocyanin and vitamin C in 'Dover', 'Campineiro', and 'Oso Grande' increased as the temperature was increased during storage, but antioxidant activity decreased and varied with the cultivars. Low temperature negatively affected anthocyanin but had a positive effect on antioxidant activity. Anthocyanins is the pigment responsible for

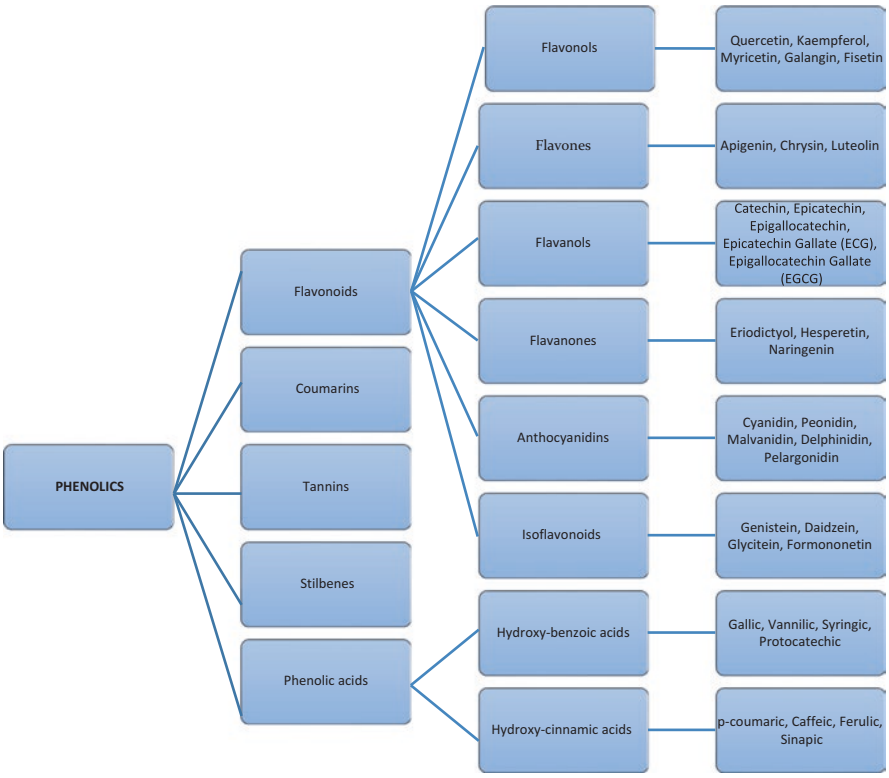

Fig. 2 Classification of phenolic compounds

the red, blue, purple, and pink coloration in plants and also guard plant tissues against abiotic-induced stress (Landi et al. 2015). In a study to test the effect of ripening stage on phytochemical compositions in 'Albion' strawberries, total flavonoids decreased from 326 to 195 mg gallic acid equivalent/100 g, while total anthocyanins increased from below levels of detection to 56.4 mg/100 g with increasing ripening stage. In this work, 28 phenolic compounds, composed mainly of glycosides, were reported. The study of Voća et al. (2014) in different strawberry cultivars 'Elsanta', 'Raurica', 'Miss', 'Arosa', and 'Marmolada' showed that anthocyanin pelargonidin 3-glucoside was dominant, ranging between 1070 and 3360 mg/100 g, followed by pelargonidin 3-rutinoside, which recorded between 236.5 and 853.3 mg/100 g and cyanidin 3-glucoside, which recorded 359.96–884.1 mg/100 g. The highest values were reported in 'Marmolada', 'Arosa', and 'Raurica'. Also, a decrease in these values was reported in the second season of the trial. Furthermore, caffeic, chlorogenic, and ellagic acid were the dominant phenolic acids, with 'Arosa' recording the highest values of caffeic acid (658.4 and 652.6 mg/100 g) in the first and second years, respectively. These results and others indicate the various effects that climatic conditions exert on the antioxidant properties of strawberry fruits.

In Korean pears, catechin (flavanol), caffeic, chlorogenic, and gallic acid (phenolic acids), as well as arbutin (glucoside), were reported in ten pear cultivars (Sun-Hee and Seung-Hee 2016). However, the total phenolic contents ranged between 60.6 mg/100 g in 'Jules d'Airolles' and 161.2 mg/100 g in 'Cheongbae'. In addition, arbutin was the most abundant phenolic compound, recording 124.45 mg/100 g. In the 'Yali' pear from China, the total phenolics generally decreased in response to storage; for example, chlorogenic acid, the most abundant phenolic compound, decreased from 1486 mg/100 g to 1285 mg/100 g over a period of 5 months. Also, quercitrin decreased from 20.7 to 16.51 mg/100 g, morin from 75.47 to 51.62 mg/100 g, and quercetin from 18.96 to 14.06 mg/100 g, but phloretin xyloglucoside increased from 12.88 to 17.89 mg/100 g (Chen et al. 2006). Ju (1991) also reported a decrease in phenolic acid with fruit maturity. However, it has also been reported that a change in the phenolic composition in pear fruits has no effect on the flavor of the fruit (Chen et al. 2006).

Apples are reportedly high in polyphenolic antioxidants, although these are reportedly high in the peels in comparison to the pulp (Eberhardt et al. 2000; Tsao et al. 2003). In Greece, Drogoudi et al. (2008) reported the highest phenolic contents in the 'Starkrimson' (0.20 mg/100 g) cultivar and the lowest in 'Golden Delicious' (0.14 mg/100 g) and 'Granny Smith' (0.08 mg/100 g) apple peels, while in the pulp, 'Fyriki' had the highest values (0.12 mg/100 g) and the least values were reported in 'Mutsu' (0.06 mg/100 g) as well as in 'Starkinson' (0.05 mg/100 g). Chinese apples' total phenolic compounds ranged between 262.1 and 882.7 mg/100 g in the 'Granny Smith' and 'Ralls' cultivars (Wu et al. 2007). These authors reported phenolic acids (chlorogenic acid, coumarin, and caffeic acid), flavanols (epicatechin and catechin), and a flavonoid (phloridzin), while chlorogenic acid and epicatechin were the most abundant phenolics in the 'Ralls' (409.6 mg/100 g) and 'Granny Smith' (404.0 mg/100 g) cultivars. However, it has been reported that phenolic acid contents are largely unaffected by maturity or storage and remain stable during this

period (Zhang 1990). However, total phenols considerably increased in response to cold storage and controlled atmosphere in Polish apple peel cultivars 'Jonagold' and 'S'ampion' (Leja et al. 2002).

Anthocyanins, phenolic acids, flavonols, and flavanols have been reported in South African plum cultivars (Venter et al. 2013).In the Serbian 'Stanley' plum cultivar, anthocyanins ranged between 5 and 57 mg/100 g and the total phenolic content between 70 and 214 mg/100 g. In this study, anthocyanins increased from 5.01 to 54.72 mg/100 g between 2008 and 2009 and decreased to 10.35 mg/100 g in 2010, while total phenolics increased from 72.42 and 211.07 mg/100 g between 2008 and 2009 and decreased to 193.68 mg/100 g in 2010 (Miletić et al. 2012). Total phenolics ranged from 174 to 375 mg/100 g, while total flavonoids ranged between 118 and 237 mg/100 g in the American plum cultivars 'French Damson', 'Stanley', 'Yugoslavian Elite T101', 'Cacak Best', 'Long John', and 'Beltsville Elite B70197' (Kim et al. 2003). Vasantha Rupasinghe et al. (2006) reported a range of 86–413 mg/100 g for total phenolic compositions in some European plum cultivars. Total phenolics ranging from 16,310 to 33,230 mg/100 g have been reported in 'Wickson' and 'Angelino' peels, respectively, while 2200 to 7690 mg/100 g was reported in 'Wickson' and 'Black Beaut', respectively, in the pulp of Californian plums (Gil et al. 2002). Similar to the study of Gil et al. (2002), the study of Cevallos-Casals et al. (2006) showed that the peels sometimes had higher concentrations of phenolic compounds than the pulp and this report agrees with those of other fruits reported in this study, including pears and apples.

Carotenoids

Like phenolic compounds, carotenoids (Fig. 3) are plant secondary metabolites with numerous functions in both plant and human physiology. In plants, the concentrations as well as the interactions of carotenoids and chlorophyll are known to be responsible for the red, orange, and yellow coloration. However, in humans, these have been linked to antioxidant activity, the immune system, intercellular communication, disease risk reduction (especially some cancers), and healthy eyesight, among others (Johnson 2002; Saini et al. 2015; Viana et al. 2013).

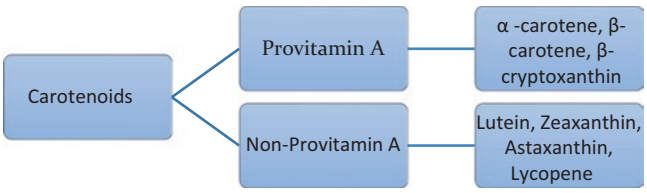

Fig. 3 Classification of carotenoids

Although apples are generally known to be low in carotenoids, it has been shown that carotenoids are high at the onset of development in the fruits but are lost as they mature (Ampomah-Dwamena et al. 2012). In some French, Italian, and Spanish cultivars, the study of Delgado-Pelayo et al. (2014) showed that green and red apple peels had higher carotenoid values ranging up to 615.3 mg/100 g of lutein in the 'Granny Smith' cultivar and up to 383.9 mg/100 g diesterified xanthophylls in the cultivar 'Ariane'. In the same study, yellow apples had higher diesterified xanthophylls (251.5 mg/100 g) in the pulp, although this was not significantly higher than in the peels. This study indicates that peeling apples significantly reduces carotene intake. It has also been shown that on-tree ripening in Russian apples decreased carotenoid compositions while detachment from the tree caused a significant increase of the pigment, and this was closely related to the on-tree chlorophyll composition at the point of harvest (Solovchenko et al. 2005). In South African apples, Hamadziripi et al. (2014) reported that 'Granny Smith' had the highest carotenoid content (354 mg/100 g) in apples harvested from the inner canopy, although this did not differ significantly from those harvested from the outer canopy. However, in the 'Golden Delicious' and 'Starking' cultivars, outer canopy apples had higher contents (264 and 222 mg/100 g, respectively), although this was lower than that of the 'Granny Smith' cultivar.

In Red Chinese 'Meirensu' pears, Huang et al. (2009) showed that covering the pears in bags for up to 3 weeks prior to harvesting had a decreasing effect on carotenoids. The pears that were covered by the black bag, white bag, and the control recorded 1.60, 2.69, and 6.25 mg/100 g, respectively. However, these authors concluded that covering the pears in bags impermeable to light during early development and removing them about 10 days before harvesting would have a positive effect on the phytonutrients, including pigments such as carotenoids. These results indicate the light-dependant nature of these fruits on the overall fruit quality.

The study of Gil et al. (2002) of some California peaches showed that β-carotene was between 2.65–3.79 mg/100 g and 0.53–1.68 mg/100 g in the peels and flesh of the 'Rich Lady' and 'September Sun' cultivars, respectively. Also, β-cryptoxanthin was 0–0.36 and 0–0.16 mg/100 g in the peels and flesh, respectively, in the 'Rich Lady' cultivar. In the plums, β-carotene ranged from 2.17 to 4.10 mg/100 g and from 0.40 to 1.88 mg/100 g, respectively, in the peels and flesh in the 'Black Beauty' cultivar. On the other hand, β-cryptoxanthin ranged from 0.03 to 0.39 mg/100 g and from 0.003 to 0.13 mg/100 g in the peels and flesh of the plums in the 'Santa Rosa' and 'Black Beauty' cultivars, respectively. These studies further indicate that peeling these fruits drastically lowers their carotene compositions.

In peaches cultivated in Texas, Vizzotto et al. (2006) reported between 0.01 and 1.8 mg/100 g as well as between 2 and 3 mg/100 g β-carotene content in red and yellow flesh peaches, respectively. In a study of Italian peaches and nectarines, Di Vaio et al. (2008) revealed that carotenoids generally insignificantly decreased in response to storage (refrigeration). Specifically, β-carotene slightly decreased from 0.062 to 0.061 mg/100 g in 'Crimson Ladd', while β-cryptoxanthin also slightly decreased from 0.028 to 0.027 mg/100 g in 'Lolita'. However, lutein slightly increased from 0.027 to 0.028 mg/100 g in 'Springcrest' and 'Lolita', respectively.

However, total carotenoids decreased from 0.12 to 0.11 mg/100 g after refrigeration. A study of New Zealand peaches, plums, and nectarines also showed that heating, freezing, and freeze-drying these fruits did not have a significant effect on their carotenoid compositions. In their study, Leong and Oey (2012) showed that β-carotene, β-cryptoxanthin, α-carotene, lycopene, and lutein either increased or decreased insignificantly by a value of 0.01 in peaches and plums, while in nectarines, the change was between 0.01 and 0.06. The compositions ranged between 0.02 and 0.04 mg/g in peaches and plums and between 0.02 and 0.09 mg/g in nectarines. These studies further indicate that storing these fruits does not have a significant impact on their carotenoid compositions. Carotenoids are low in strawberry fruits, with compositions reportedly below 1 μg/g (Lado et al. 2016). Zhu et al. (2015) and García-Limones et al. (2008) reported a decrease in β-carotene, lutein, zeaxanthin, and β-cryptoxanthin as the fruit matures in Japanese and Spanish strawberries.

Health, Absorption, and Bioavailability of Phytochemicals

Due to their rich nutritional and therapeutic properties, the inclusion of fruits in the diet conceivably enhances their health benefits in human physiology. The recent interest in phytochemicals; the non-nutritive dietary components found in fruits including vegetables, has seen an increase in research on their attributes. This is because, after consumption of the fruits, the phytochemicals should ideally be absorbed into the system. In fact, Wang et al. (1996) reported that phytochemicals, which act either individually or in combination, are the principal antioxidant activity contributor of fruits in comparison with vitamin C. Phenolic antioxidant activities have been shown to chelate and stabilize divalent cations, inhibit lipoxygenase, and scavenge free radicals (Ozcan et al. 2014). Furthermore, flavonoids, phenolic acids, and tannins have been shown to be anticarcinogenic and antimutagenic. Noroozi et al. (1998) reported the synergistic protective effects of L-ascorbic acid and flavonoids against oxidative DNA damage of lymphocytes. However, the absorption and bioavailability of some phytochemicals, such as anthocyanins, is reportedly low, while their metabolism is not implicit (Wu et al. 2002). Furthermore, the antioxidant capacity of some fruit extracts, such as strawberries, has been shown to be positively related to their antiproliferative activities. Azzini et al. (2010) also showed that the consumption of strawberries in fresh form resulted in an increase in α-carotene, while both fresh and stored forms increased vitamin C. These authors concluded that storage had an effect on phytochemicals and their bioavailability in fruits. Moreover, Johnston et al. (2000) reported that only a quarter of vegetables that are consumed supply favorable quantities of phytochemicals required to achieve desirable effects, and this amount increases to 50% in fruits. β-Cryptoxanthin and lutein bioaccessibility in some edible aromatic plants were found to be better than β-carotene (Daly et al. 2010). In some apples, Bouayed et al. (2011) reported that, after gastrointestinal digestion, phenolic availability decreased. In their study, these authors showed that the gastric phase led to the release of polyphenols, while a minor additional release occurred during intestinal digestion. Phytochemical

bioaccessibility and bioavailability appears to be affected by processing, health of the intestines, chemical structure, molecular weight, food matrix, amount consumed, as well as the physiological standing of the consumer (Li et al. 2012). However, Carbonell-Capella et al. (2014) reported that the bioavailability of compounds process, which ends with excretion, begins with gastrointestinal liberation, followed by absorption, tissue distribution, and metabolism. However, the bioavailability of different compounds appears specific. According to the same authors, the bioavailability of different classes of polyphenols, for example, has been reported to be determined by esterification, molecular weight, and glycosylation. Some authors also report that, although the prevalence of polyphenols in the diet is not directly dependant on their physiological activity, polyphenols are generally poorly metabolized or absorbed in the colon, leading to their rapid excretion in the urine or bile (Crozier et al. 2010; Karaś et al. 2017). However, the physiological activity of polyphenols does not depend directly on their prevalence in the human diet. Indeed, these polyphenolic compounds are poorly absorbed from the colon or metabolized and are rapidly excreted from the body (Marín et al. 2015). In general, genetic composition of the fruit, environmental conditions, and pre- and postharvest processing play an important role in the final amount of absorbed phytochemicals, and these factors, in turn, have an impact on the health of the consumer.

The phytonutrient compositions of temperate fruits discussed in this chapter indicate their possible role in providing a balanced diet and some health benefits. Various studies have been conducted on the role of fruits in human health. Lin and Morrison (2002) reported a positive correlation between daily fruit consumption and a reduction in body mass index. The association between fruits and vegetables consumption and reduced functional deteriorations related with ageing have also been widely reported. Liu (2003) proposed that the anticancer and antioxidant activities derived from fruits are a result of the synergistic and additive effects of phytochemicals found in fruits. In this study, ascorbic acid from apples with skin accounted for about 0.4% of the total antioxidant activity, indicating that most of these activities are derived from flavonoids and phenolics in apples. The fiber supplied by these fruits when consumed whole has been linked with a reduction in cardiovascular diseases as well as obesity (Slavin and Lloyd 2012). While the phytonutrient compositions of fruits vary widely, their consumption in combination have the potential to reveal their full potential in human health and physiology. Although many antioxidant-containing extracts and pills have been developed and are widely available on the market, Liu (2004) concluded that antioxidants are best acquired through the consumption of whole fruits.

Conclusion

Temperate fruits are endowed with numerous nutritional and therapeutic components in the form of phytonutrients. These have been widely documented, although some mechanisms involved are yet to be fully comprehended. Although the phytonutrient compositions of fruits have been documented, they are either not well

known or, if known, consumption of the fruits is very low. In fact, globally, the minimum daily requirements of fruits and vegetables required to complete a balanced and healthy diet are a major challenge whose targets are yet to be met. Several reports have indicated the antioxidant activities associated with phytochemicals, such as phenolics and carotenoids, while their anticarcinogenic properties and antiproliferative as well as cardiovascular benefits have also been documented. Although the consumption of fruits is important, it is more important to understand how much of the phytonutrients that are consumed in fruits end up being absorbed into the system and the mechanisms of action involved. These are yet to be fully understood. Understanding the bioavailability and absorption of phytonutrients in fruits will help develop strategies to enhance and optimize their use. It is also clear from numerous studies that genetic composition, environmental factors, pre- and postharvest treatment of fruits, as well as processing, affect the phytonutrient compositions of fruits. This, in turn, affects phytonutrient bioavailability as well as absorption and, eventually, balanced diets and health. It is, therefore, important to develop pre- and postharvest measures including the environment, as well as processing, that improve the phytonutrient compositions of fruits and their bioavailability and eventual absorption. The general populace needs to be educated on the nutritional and therapeutic benefits of fruits in order to encourage their consumption. The ongoing debate on sugar tax should be turned into a global and effective campaign to discourage the present high consumption of sugar-added drinks and substituting with fruits. These measures will conceivably help to optimize the nutritional and health benefits of fruits and lower the present high economic costs associated with the consumption of unhealthy and unbalanced diets.

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Postharvest Technologies for Shelf Life Enhancement of Temperate Fruits

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Introduction

Temperate fruits, for instance, apple, pear, peach, plum, and strawberry, are adapted to climates in the mid-latitudes zone. Temperate fruits have two climatic adaptations to complete their life cycle. First, they need cold periods during the dormancy period, which limits their growing in tropical zones, and, second, they require variant change in the degree of winter hardiness, and these conditions are met in cold climatic zones. On the contrary, tropical fruits are usually harmed by above-zero low temperature, since they are so sensitive to cold weather. The quality attributes of fresh fruits include appearance, texture, flavor, and nutritive value. Appearance factors include size, shape, color, and freedom from defects and decay. Texture factors include firmness, crispness, and juiciness. Flavor components incorporate sweetness, acidity, astringency, bitterness, aroma, and off-flavors. Nutritional quality is determined by a fruit's content of vitamins (A and C are the most important in fruits), minerals, dietary fiber, carbohydrates, proteins, and antioxidant phytochemicals, which include carotenoids, flavonoids, and other phenolic compounds.

Safety factors that may influence the quality of fresh fruits include residues of pesticides, presence of heavy metals, mycotoxins produced by certain species of fungi, and microbial contamination. Losses in fresh fruits between harvest and processing may be quantitative (e.g., water loss, physical injuries, physiological breakdown, and decay) or qualitative (e.g., loss of acidity, flavor, color, and nutritive value). Many factors influence fruit quality and the extent of postharvest losses that can occur in the orchard, during transportation, and throughout the handling system

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(sorting, sizing, ripening, cooling, and storage). The total time between harvesting and processing may also be an important factor in maintaining the quality and freshness. Minimizing the delays throughout the postharvest handling system and the use of postharvest technologies management greatly reduces quality loss, especially in highly perishable fruits, such as strawberries, raspberries, blackberries, apricots, and cherries.

Based on their growth habit, temperate fruits are categorized into three categories: tree fruits (such as apple, pear, plum, and peach), vine fruits (e.g., grape and kiwifruit), and small fruits, which refers to the plant's size and not necessarily the fruit, for instance, strawberry, raspberry, currant, and blueberry.

Tree Fruits

Tree fruits belong to the rose family (Rosaceae) and they include the pome and stone fruits. Pome fruits (i.e., apple, pear, quince, and loquat) are characterized by a fleshy outer portion, which is formed by the expansion of floral parts and receptacle. All stone fruits (almond, apricot, cherry, peach, nectarine, and plum) are members of the genus *Prunus* and they are commonly named as 'stone fruits' because they have a stony pit which encloses a solitary seed.

Apple (*Malus* × *domestica*) is the first known fruit of the pome fruits and it has been known since antiquity. It is grown in northern China and Siberia, where temperatures fall to about −40 °C during the winter season, in high elevation locations such as Colombia, and, on the either hand, on the equator, where two crops can be produced.

Pear (*Pyrus* species) is as old a fruit crop as apple and both are consumed in similar ways; however, pear is somewhat less popular in the West. Pears are divided into European pear (*P. communis*) and Asian pear (*P. pyrifolia* and *P. ussuriensis*). The European pears are usually consumed when they soften after harvest, while the Asian pears are consumed when crisp.

The quince (*Cydonia oblonga*) comes in the third place of importance among the pome fruits and they are usually grown in warm climates and can be consumed raw. Despite this, quinces are not very popular because their tastes are sour and they are astringent before ripe.

Peach (*Prunus persica*), which has become the most popular temperate summer fruit, originated from China and was introduced to Europe via Persia in the first century. There are many types of peaches. The free-stone types, which have melting yellow or white flesh, are usually consumed fresh and the second one, the cling-stone types with rubbery flesh, are used in processing; the nectarine, which is characterized by non-fuzzy skin, resulted from a mutation, and Peento, a flat peach with a saucer shape, is another variant.

Almond (*Prunus amygdalus*) originated from the hot regions of Western Asia, but it was prehistorically introduced to Greece and West Africa. Its flesh is leathery and inedible, and its fruits are consumed when quite immature, especially in Arabian

countries. Not alike the majority of stone fruits, almonds' seeds have a non-bitter taste and are the consumed part of this fruit, so this species is categorized under nuts. The almond is extensively grown in California and is widely planted in Mediterranean countries.

Cherries, one of the most popular early summer fruits, comprise about 30 species. Among the edible types of cherries, there is sweet cherry (*Prunus avium*), tart (sour) cherry (*P. cerasus*), ground cherry (*Prunus fruticosa*), and duke cherry, which is a hybrid between sweet and tart cherries. Cherries could have yellow, red, or yellow-red bicolor and are consumed fresh, dried, or processed. There are also some semi-processed cherries, such as maraschino cherry, in which cherries are brined, bleached, and then colored, as well as flavored with almond oil.

Apricot (*Prunus armeniaca*), which is native to central Asia and China, is characterized by its soft velvet skin and is consumed fresh, dried, or processed. The apricot blooms very early, is quite sensitive to spring frost, and is difficult to grown on a large scale in such areas. This could be part of the reason why apricot does not have the same degree of importance as peach, cherry, and plum. The beautifully flowered Chinese plum is considered more as an apricot type rather than a plum type.

Plums comprise a diverse group of fruits based on their origins (Europe, Asia, and America). Among the European species, *Prunus domestica*, such as greengage and prune types, and *P. insititia*, which includes bullaces, damsons, mirabelles, and St. Julien types, are characterized by having six sets of chromosomes. Asiatic species contain *P. salicina* and *P. simonii* (apricot plum); the former includes both green- and red-fleshed Japanese plums, while the latter is cultivated in China. However, there are many American plum species, with none of them being widely planted. Most of the plum industry is mainly based on *P. domestica* in Europe and *P. salicina* in Asia. Plums could be consumed either fresh or dried. The dried plums without fermentation are called plum prunes. Their drying process is run under very low moisture levels, so they can be stored for long periods of time.

Vine Fruits

Grapes (*Vitis vinifera*), one of the most important temperate fruit species, are usually grown on trellises. *Vitis vinifera* have been popular for wine production for a long time. However, while any sweet fruit can be used in wine production, the grape is always the preferred species because it has a unique combination of sugars, acids, and astringent substances. Due to this, producers are always reluctant to change the cultivars of grapes to avoid changing the standard characteristics of their produced wine. Grapes can be eaten fresh, especially the seedless varieties. The large-fruited table grape Italia, widely appreciated in Europe, has a Muscat flavor which is sweet and pleasant. Recently, non-alcoholic grape juice, produced from the American species *V. labrusca*, has become common in the US market.

Kiwifruit (*Actinidia deliciosa*) has recently been domesticated. It is derived from a Chinese fruit called Yang Tao, which was collected rather than cultivated. New Zealand growers succeeded in domesticating the crop by selecting suitable male and female clones, as well as techniques for cultivation. After this early adoption, the fruit received a new name, kiwifruit, referring to Kiwi, the popular flightless bird of New Zealand. Kiwifruit has a pleasant but weak flavor and a unique sliced shape, so it has been used in cake decoration or as a component of fruit salad, which has made this fruit globally popular. The fruit is also characterized with the ability of long storage life and this is what makes it possible for New Zealand to export it throughout the four seasons.

Small Fruits

Strawberry is an important small fruit in most temperate climates. Its fruit size has greatly increased, and it has firm flesh with improved flavor and appearance. Grown in all temperate countries, the strawberries industry is focused in southern California in the United States, southern Spain, and Italy.

Blackberries and raspberries belong to the genus *Rubus*, which includes many species and a vast number of hybrids. *Rubus* is very diverse and its cultivated species are known as brambles, which include black raspberry (*R. occidentalis*), blackberry (*Rubus* species), and various interspecific hybrids between raspberry and blackberry, such as loganberry, boysenberry, and tayberry.

Blueberry (various species) is native to the United States and grows in bushes of various heights. The cranberry (*Vaccinium macrocarpon*) is an unusual berry crop because it is grown submerged in bogs. The fruits are too acid to be eaten raw and are consumed processed as jelly or as a sauce. Lingonberry (*V. vitis-idaea* var. *minus*) is native to northern regions of Europe, Asia, and North America. The loganberry is usually considered to be a hybrid between a blackberry and a raspberry, and its principal use is for juice.

Maturity and Harvesting Indices

Maturity at harvest is one of the major factors that influence fruit composition, storage life, and final fruit quality. Harvesting at the ideal moment is very important for the development of quality after harvest and for a long postharvest life. When harvested late, fruits may not have a sufficiently long postharvest life. Fruits harvested too early or too late in the season are more subject to physiological disorders and have a shorter storage life than those picked at optimum physiological maturity. Most fruits attain a great eating quality when harvested fully ripe, usually picked at the mature stage, but may also be picked when not ripe to decrease mechanical damage during postharvest handling. Moreover, mechanical harvesting procedures

may also damage fruit; thus, the choice of harvest method should maintain fruit quality.

Most of the maturity indices currently used are the result of a combination between the indices which ensure the best food quality to the consumer and those providing the necessary flexibility for transport and marketing. Temperate fruits could be climacteric or non-climacteric. Non-climacteric fruits are not able to continue their ripening process if removed from the tree, while climacteric fruits can be harvested mature and ripened off the plant. Examples of temperate fruit belonging to the two groups are:

- Group 1: Berries (e.g., blackberry, cranberry, raspberry, strawberry), grape, cherry.
- Group 2: Apples, pear, quince, apricot, nectarine, peach, plum.

Fruits of the first group (non-climacteric) produce very small quantities of ethylene and do not respond to ethylene treatment, while those of group 2 (climacteric) produce more significant quantities of ethylene during their ripening. In this group, ethylene treatment will result in faster and more uniform ripening. Many characteristics of fruits have been tested as maturity and harvesting indices, including morphological, anatomical, physiological, and biochemical features and components. Relevant maturity and harvesting indices are those traits or components that change during the development of the fruit, correlating closely and regularly with the quality of the fruit, and are not strongly affected by factors such as the environment. Maturity indices commonly used for most of the temperate fruits are fruit size and shape, overall and ground color of the skin, flesh color, flesh firmness, soluble solids content, starch content, acidity, etc. Some of these indices are shown in Table 1.

Table 1 Examples of maturity indices for temperate fruit

Indices	Fruits
Elapsed days from full bloom to harvest	Apple, pear
Size	Most fruits
Shape (fullness of fruit shoulders and suture)	Stone fruits
Dry weight	Kiwifruit
Color, external	All fruits
Firmness	Pome and stone fruits, berries
Compositional factors	
– Starch content	– Apple, pear
– Soluble solids content	– Pome and stone fruits, grapes, kiwifruit
– Acid content	– Most fruits
– Sugar/acid ratio	– Grape

Fruit Quality

'Quality' is a term that refers to a degree of excellence, a high level or value. Quality value and acceptance of fruits depend on the values of a combination of several attributes, such as color, appearance, flavor, texture, nutritional characteristics, and safety (Maarten 2003; Skrzyński and Konopacki 2003). Fruit color is one of the most important appearance attributes, which is due to the presence of several pigments, including carotenoids, betalains, flavonoids (anthocyanins), and chlorophyll. As consumers, fruit color typically affects our acceptance and perception of sweetness and flavor. Moreover, it can even evoke emotional feelings in humans (de Jesús Ornelas-Paz et al. 2008). Used as a ripening index, fruit color is useful in determining the harvest date and estimating the length of time for which a fruit can be stored and marketed. A large number of temperate fruits contain several pigments which are used to determine the harvesting time and maturity stage.

Fruit texture is another important quality attribute which is defined as the group of mechanical properties determining human sensations when they eat food. This attribute influences considerably the acceptability of the product to the consumer (Tijskens 2003). Cell anatomy, water content, and the composition of cell walls are the most important factors influencing fruit texture. These factors are strongly affected by ripening. Several fruit texture attributes exist, including crispness, mealiness, juiciness, and firmness (Zerbini et al. 1999). Firmness is the most important attribute of texture for fruit quality, as it decreases during storage and marketing. It also determines the mechanical properties of fruits (Gunness et al. 2009), their ability to resist the postharvest handling and resistance to mechanical damage.

Sugar content is a crucial attribute for the selection of temperate fruits. This attribute affects fruit flavors and determines the caloric value of fruits (Montero et al. 1996). The first stages of fruit development are characterized by a high concentration of starch, which is progressively hydrolyzed during ripening; resulting in an increase in the content of simple sugars, such as glucose, fructose, and sucrose.

Organic acids are also abundant in temperate fruits, mainly citric, malic, and ascorbic. Ascorbic acid is particularly important and it greatly contributes to many aspects of human health (Davey et al. 2000; Harrison and May 2009). Organic acid content decreases during ripening and is involved in the flavor, texture, pH, and color of fruits, altering their sensorial quality (Montero et al. 1996). For some temperate fruits, the ratio of sugar to acids is commonly used as a ripening index.

Temperate fruit quality is also related to the volatile compounds content. Many of them give off a wide range of volatile compounds, some of which are considered extremely important for fruit quality. The flavor of fruits depends on a combination of aroma and taste sensations. Postharvest procedures considerably affect fruit quality. In developing countries, 40–50% of horticultural crops produced are lost before they can be consumed, due to the high rates of bruising, water loss, and subsequent decay during postharvest handling (Kitinoja and Kader 2002; Ray and Ravi 2005). Several biochemical and physiological changes occur after the harvesting of temperate fruits. Most of these changes, such as cell wall degradation, water loss,

shriveling, softening, overripening, disease infestation, shelf life decreases, etc., are undesirable. These changes strongly affect fruit quality and they can be slowed down by controlling and improving postharvest handling and development of new postharvest technologies.

Postharvest Practices and Problems

Both quantitative and qualitative food losses of extremely variable magnitude occur at all stages in the postharvest system, from harvesting, through handling, storage, processing, and marketing, to final delivery to the consumer (Hodges et al. 2011). According to Kader (2002), approximately one-third of all fresh fruits are lost before they reach the consumer. Another estimate suggests that about 30–40% of total fruit production is lost in between harvesting and final consumption (Singh et al. 2014). To reduce these losses, producers and handlers must understand the biological and environmental factors involved in deterioration on a priority basis. Secondly, the use of postharvest techniques that delay senescence and maintain the best possible quality should be adopted.

Biological Factors Involved in Postharvest Deterioration of Fruits

Biological factors involved in postharvest deterioration of fresh fruit quality include the rates of respiration, ethylene production, and transpiration. In addition, several physiological disorders also reduce postharvest fruit quality. These are the result of products' responses to various environmental and physical stresses, including temperature, relative humidity, ethylene, atmospheric composition, etc. (Kader and Yahia 2011).

Respiration

Harvested fresh fruit still remains alive and performs all the functions of a living tissue. One of the metabolic functions performed in the postharvest state is respiration, by which stored organic materials are broken down into simple end products together with the release of energy. Fresh produce after harvest continues the process of respiration and transpiration until its reserves of food and water are exhausted (Sirivatanapa 2006). As a result, respiration triggers senescence, decrease in food value, reduction in flavor quality, and, especially, loss of sweetness (Arah et al. 2016). In order to reduce the impact of the respiration on the fruit deterioration,

every effort must be made to slow down the respiration rate of produce in order to minimize quality losses and extend the shelf life of the fruit. Temperature has a significant influence on the respiration rate of harvested produce and, without doubt, has the greatest impact on the deterioration of produce postharvest. As a matter of fact, temperature control has been found to be the most important factor in maintaining product quality (Kitinoja and Kader 2002). The higher the storage temperature of fresh produce, the greater its rate of respiration and, consequently, its deterioration.

Respiration rates can be reduced and maintained at a reasonable level if the product is kept at an appropriate temperature during storage. Temperature management is pivotal to controlling respiration and to maintaining quality. In addition, low levels of O_2 are required to reduce respiration rates, while, at the same time, allowing anaerobic respiration. An O_2 level of around 2–3% generally produces a beneficial reduction in respiration rates and in other metabolic reactions of fresh produce. Lower O_2 levels could lead to anaerobic respiration and off-flavor development as a result of alcohol formation.

Transpiration

Another relevant physiological process of plants is transpiration, which is the loss of water by evaporation from the plant tissues. Transpiration is the main cause of deterioration because it results in not only indirect quantitative losses (loss of salable weight), but also losses in appearance (wilting and shriveling), textural (softening, flaccidity, limpness, loss of crispness, and juiciness), and nutritional quality (Kader and Yahia 2011). The regulation of water loss is governed by the outer protective coverings, which include the cuticle, epidermal cells, stomata, lenticels, and trichomes. The thickness, structure, and chemical composition of the cuticle vary greatly among commodities and among the developmental stages of a given commodity (Kader 2002). The transpiration rate is, in part, influenced by external or environmental factors (temperature, relative humidity, air movement, and atmospheric pressure). This physiological process can be controlled by applying treatments to the commodity (e.g., waxes and other surface coatings or wrapping with plastic films) or by manipulation of the environment (e.g., refrigeration maintenance of high relative humidity and control of air circulation) (Kader 2002).

Ethylene Production

Deterioration of harvested fruits can also be caused by ethylene production. Ethylene is a natural product of plant metabolism and is produced by all tissues of higher plants. As a plant hormone, ethylene regulates many aspects of growth, development, ripening, and senescence (Abeles et al.1992). Ethylene induces fruit

softening, senescence, and the inhibition of the formation of antifungal compounds in the host tissue (Kader 1985). It alters and accelerates the natural processes of development, ripening, and senescence (Saltveit and Morris 1990). The ethylene production rate by fresh fruits can be reduced by storage at low temperature (below 30 °C), and by reduced O_2 (less than 8%) and elevated CO_2 (above 1%) levels in the storage environment around the commodity (Kader and Barett 2005). Since July 2002, the ethylene action inhibitor, 1-methylcyclopropene (1-MCP), under the trade name 'SmartFresh', at concentrations up to 1 ppm, was approved by the United States Environmental Protection Agency for use on apples, apricots, kiwifruit, nectarines, peaches, pears, persimmons, and plums. The first commercial application has been on apples to retard their softening, scald development, and extend their postharvest life (Kader and Barett 2005).

Postharvest Disorders

Fresh fruits are subjected to various postharvest disorders, which include physiological and pathological causes. Most of these problems can be reduced or controlled if appropriate practices are implemented pre- and postharvest.

Physiological Disorders

Physiological disorders of fruits arise from exposure of the commodities to undesirable postharvest environmental conditions or mineral imbalance arising during growth (Wills et al. 2007). Improper temperatures may lead to disturbance in the normal metabolism of the harvested products and cause physiological disorders known as 'chilling injury and freezing injury' (Watada 1982). Freezing injury results when the fruits are held below their freezing temperatures (Kays and Paull 2004). The disruption caused by freezing and the formation of ice crystals in tissues usually results in immediate collapse of the tissues and total loss of the commodity. Chilling injury, on the other hand, is induced by low (below 10–13 °C) but non-freezing temperature (Wang 1993). The symptoms of chilling injury become more noticeable upon transfer to higher (non-chilling) temperatures. The most common symptoms are surface and internal discoloration (browning), pitting, water-soaked areas, uneven ripening or failure to ripen, off-flavor development, accelerated incidence of surface molds, and decay. Heat injury is induced by exposure to direct sunlight or excessively high temperatures. Its symptoms include bleaching, surface burning or scalding, uneven ripening, excessive softening, and desiccation. Certain types of physiological disorders originate from preharvest nutritional imbalances. Calcium is associated with more postharvest-related deficiency disorders than any other mineral (Kader 2002; Wills et al. 2007). For example, blossom end rot of tomatoes and bitter parts of apples result from

calcium deficiency and are well known as calcium deficiency disorders in horticultural crops (Kader 2002; Wills et al. 2007). The calcium content influences the textural quality and senescence rate of fruits, whereas increased content has been associated with improved firmness retention, reduced CO_2 and C_2H_4 production rates, and decreased decay incidence.

Oxygen and carbon dioxide levels can also induce respiratory disorders associated with very low O_2 (below 1%) and/or high CO_2 (above 20%) concentrations in and/or around harvested produce in storage or packaging conditions (Kader and Saltveit 2003).

Pathological Breakdown

Pathological breakdown caused by disease-causing organisms (mainly fungi and bacteria) may cause infection before, during, or after harvest. One of the most common and obvious symptoms of deterioration is due to bacteria and/or fungi infection (Kader 2002; Wills et al. 2007). The most common fungi pathogens that cause decay of fruits include different species of the fungi *Alternaria*, *Botrytis*, *Penicillium*, *Rhizopus*, *Colletotrichum*, *Monilinia*, *Diplodia*, and *Sclerotinia*, and of the bacteria *Erwinia* and *Pseudomonas* (Wills et al. 2007). In general, fruits exhibit considerable resistance to potential pathogens during most of their postharvest life. The onset of ripening and senescence in fruits renders them susceptible to infection by pathogens. Stresses such as mechanical injuries, chilling, and sun scald lower their resistance to pathogens (Kays and Paull 2004; Wills et al. 2007). Although most pathogens totally rely on physical injury or physiological breakdown of the commodity to invade host tissues, a few such as *Colletotrichum* spp. are able to actively penetrate the skin of healthy product (Kader 2002). Microbial infection can occur before and/or after harvest. Latent infection, or quiescent infection, is the state in which a product is infected prior to harvest with no obvious symptoms developing until the pathogens are reactivated by the onset of conductive conditions, such as fruit ripening or favorable temperatures (Kays and Paull 2004; Wills et al. 2007).

Environmental Factors Affecting Deterioration

Many environmental parameters surrounding the produce have direct effects on quality preservation as well as on its rapid deterioration. These parameters include, among others, temperature, relative humidity, atmospheric composition, and ethylene.

Temperature

Temperature is the main environmental factor that directly influences many processes of harvested commodities following the temperature coefficient Q_{10}, which indicates that, with each increase or decrease in the storage temperature by 10 °C, the rate of deterioration increases or decreases accordingly by two- to threefold (Wills et al. 2007). The exposure of fresh produce to undesirable temperatures results in many physiological disorders, such as chilling injury at low temperatures and senescence at higher temperatures. The spore germination and growth rate of pathogens are greatly influenced by temperature; for instance, cooling commodities below 5 °C immediately after harvest can greatly reduce the incidence of *Rhizopus* rot. The temperature also influences the effect of C_2H_4, reduced O_2, and elevated CO_2. Thus, postharvest storage of fruits at appropriate low temperature has been the main strategy to maintain their quality and extending their shelf life as a consequence of slowing down the rates of their respiration and water loss, as well as the growth of decay microorganisms (Kays and Paull 2004; Wills et al. 2007).

Relative Humidity

The relative humidity (RH) is the moisture content of the atmosphere surrounding the commodity. It is expressed as a percentage of the amount of moisture that can be retained by the atmosphere (moisture holding capacity) at a given temperature and pressure without condensation. The moisture holding capacity of air increases with temperature. The rate of water loss from fruits depends on the vapor pressure difference between the commodity and its environment, which is affected by temperature and RH (Kader 2013). Low water loss can be achieved by reducing the vapor pressure difference between the product and air via lowering the temperature and/or raising RH (Kader 2002; Kays and Paull 2004; Wills et al. 2007). RH can influence water loss, decay development, incidence and severity of some physiological disorders, and uniformity of fruit ripening. Despite the fact that maintenance of a high RH atmosphere is necessary to arrest water loss, very high RH (above 95%) can encourage the proliferation of bacteria or fungi and other pathological breakthrough (Kader 2002; Wills et al. 2007). The appropriate RH range for the storage of fruits is between 85 and 95% (Kader 2013).

Atmospheric Composition

Alteration in the concentration of the gases surrounding horticultural products can significantly increase their storage life, resulting from reduction in the respiration rate of produce and retardation of senescence and growth inhibition of many

spoilage microorganisms. The combination of different gases such as O_2, CO_2, N_2, and ethylene in a storage environment is very important in extending the storage life. The levels of these gases in the atmosphere can be manipulated through controlled atmosphere (CA) or modified atmosphere (MA). CA or MA refers to a controlled addition or removal of gases in the storage environment, resulting in an atmospheric composition different to that of air (Kader 2002; Kader and Saltveit 2003; Wills et al. 2007). In practice, CA and MA usually involve reducing O_2 levels below 5% and/or elevating CO_2 levels above 3% (Kader and Saltveit 2003). CA and MA are considered as an adjunct to refrigerated storage and not substitutes for proper temperature and RH management (Kader 2002; Kader and Saltveit 2003). The beneficial effects of CA and MA storage include prolonged storability of perishables by reducing respiration, senescence, water loss, ethylene production, decay invasion, and growth of fungi and bacteria. However, when CA or MA are incorrectly used, they will aggravate physiological disorders such as irregular ripening, off-flavor development, and increase susceptibility to decay (Kader 2002; Kader and Saltveit 2003; Wills et al. 2007).

Ethylene

The presence of ethylene in the atmosphere has been a major concern for fruits during the postharvest handling because it accelerates ripening, senescence, abscission, and physiological disorders (Kader 2002; Kays and Paull 2004). The action of ethylene must be avoided for most fruit crops during storage and transportation. A simple physical method to prevent ethylene accumulation is to ensure good air circulation inside the storage room and ventilation with external air if needed (Wills et al. 2007). Ethylene absorbents, such as potassium permanganate on vermiculite in packages, have been tested with success to oxidize the ethylene release from fresh products (Wills et al. 2007). During the last decade, the successful registration and commercialization of 1-MCP for application in edible horticultural products has opened an exciting new era of reducing ethylene damage in marketing quality and storage life of fruits after harvest (Blankenship and Dole 2003; Reid and Staby 2008; Wills et al. 2007).

Postharvest Technologies for Temperate Fruit Management

Development of the Cold Chain

Cooling methods are used to remove field heat from harvest crops to be near to its optimum storage temperature. Different cooling facilities are used for this purpose (Wills et al. 2007).

Reducing the time between picking and initial cooling is particularly critical to minimize transpiration and respiration observed at high field temperatures (Maxie et al. 1959; Harvey and Harris 1986; D'Souza and Ingle 1989). Highly temperate (perishable) fruits, such as strawberries, bush berries, cherries, and apricots, should be cooled to near 0 °C (32 °F) within 6 h of harvest. Other fruits should be cooled to their optimum temperature within 12 h of harvest.

The produce is usually cooled to its long-term storage temperature in special facilities designed to rapidly remove heat. Cooling can be done using cold water (hydrocooling) or cold air (forced-air cooling or pressure cooling).

Precooling Methods

Room Cooling

The use of a regular cold storage room for precooling is not always advisable, as fruit will not be cooled for an appropriate period of time. Precooling can take several days if the system is not powerful enough to remove field heat as quickly as possible and may induce some postharvest disorders. The speed of precooling depends on the temperature of the fruit, temperature of the room, respiration rate of the fruit, air circulation within and inside packages, etc.

Forced-Air Cooling

Forced-air cooling or pressure cooling, is the most widely adaptable method and is commonly used for many fruits, fruit-type vegetables, and cut flowers (Parsons et al. 1970, 1972; Rij et al. 1979; Thompson et al. 1998). Refrigerated air is used as the cooling medium in this system. It is forced through produce packed in boxes or pallet bins. A number of air flow systems are used, but the tunnel cooler is the most common (Thompson et al. 1998). Two rows of packages, bins, or palletized product are placed on either side of an air-return channel. The product is cooled in batches. The cooling time ranges from 1 h for cut flowers to more than 6 h for larger fruit, packed in air flow-restricting materials, such as bags or paper wraps.

Hydrocooling

A hydrocooling system requires cold water as the cooling medium. It is a very efficient method for fast precooling and the medium is directly in contact with the produce. Cooling is accomplished with this technique by moving cold water around produce with a shower system or by immersing produce directly in cold water. Shower coolers distribute water using a perforated metal pan that is flooded with cold water from the refrigeration evaporator (Thompson et al. 1998). Shower-type coolers can be built with a moving conveyor for continuous flow operation, or they can be

operated in a batch mode. Immersion coolers are suited for produce (e.g., apples) that sinks in water (Thompson et al. 1998). Water is a better heat transfer medium than air, and, consequently, hydrocoolers cool produce much faster than forced-air coolers. In well-designed shower coolers, smaller fruits of lower diameters, such as cherries, cool in less than 10 min. Large diameter products like melons cool in 45–60 min (Stewart and Couey 1963; Thompson et al. 1998). Some constraints of hydrocooling are related to packaging materials, which are required to tolerate water contact or to be water resistant, such as plastic or wooden crates or bins. Packages for hydrocooled produce must allow vertical water flow and tolerate water contact.

Corrugated fiberboard must be waxed to withstand water contact. Hydrocooler water may be a source of microbial contamination and, thus, must be obtained from a clean source and treated with hypochlorous acid from sodium hypochlorite or gaseous chlorine to minimize the levels microorganisms (Thompson et al. 1998). It is commonly used for root, stem, and flower type vegetables, melons, and some tree fruits (Perry and Perkins 1968; Mitchell et al. 1971).

Storage

Short- or long-term storage of fresh fruits may be needed before processing to regulate the product flow and extend the processing season. Classification of fresh fruits according to their optimum storage temperature and potential storage life is shown in Table 2. In all cases, the relative humidity in the storage facility should be kept between 90 and 95%. To reduce decay, elevated CO_2 (15–20%) may be added to the atmosphere within pallet covers for strawberries, bush berries, and cherries, whereas sulfur dioxide (200 ppm) fumigation may be used on table grapes.

There is a continuing trend toward increased precision in temperature and RH management to provide the optimum environment for fresh produce during cooling, storage, and transport. Precision temperature management tools, including time–temperature monitors, are becoming more common in cooling and storage facilities. Several manufacturers have developed self-contained temperature and RH monitors and recorders, which are small and can be packed in a box with the product. Data are read by connecting these units to a personal computer with the appropriate software made by the manufacturer. Infrared thermometers are used to measure the surface temperature of products from a distance in various locations within storage facilities. Electronic thermometers (with very thin, strong probes for fast response) are used for measuring the product temperature during cooling, storage, and transport operations.

Table 2 Classification of fruits according to their optimum storage temperatures and potential storage life (Barrett et al. 2005)

Potential storage life (weeks)	Optimum storage temperatures (0–2 °C)
<2	Apricot, bush berries, strawberry, fig
2–4	Nectarine, peach, plum
4–6	Grape
>6	Apple (non-chilling-sensitive cultivars), pear, cranberry, kiwifruit

Ventilated Storage

Naturally ventilated structures are still used in some countries for the storage of a variety of crops. In ventilated storage, controlled ambient air is applied for the cooling of the produce and maintenance of lower temperatures. Any type of building can be used, provided that it allows the free circulation of air through the structure and its contents. The capital investment and operating costs needed for such facilities are much lower than for mechanically refrigerated stores, and the method is suitable for some fruits marketed locally or stored for a very short period. This method requires continuous inspection and sorting to minimize losses. If feasible, insulated walls are to be used to provide better insulation, otherwise the structure needs to be shaded by trees or, alternatively, a proper covering material is to be used to provide insulation from the heat of the sun (Yahia and Elansari 2011). Harvesting should be carried out at the optimum maturity stage and there should be no delay between harvest and storage.

In general, fruits are very susceptible to moisture loss in storage, and they become dry and hard compared to those stored in mechanically refrigerated storage (Alhamdan and Al-Helal 2008).

Mechanically Refrigerated Storage

Mechanically refrigerated storage is a thermally insulated space equipped with refrigeration units that allow cold air to circulate and can be used both as a storage and a precooling method. However, it is important to note that precooling and refrigerated storage are two different stages in the postharvest cold chain that have very different requirements. However, it is considered to be the slowest cooling method, as the bulk or containerized commodity has to be placed in a refrigerated room for several hours or days (Talbot and Chau 2002). There are many ways to circulate the cold air inside a room, depending on the type of the evaporative coil. For tropical and subtropical fruits, the method most commonly applied to cool a warehouse space is to install ceiling air coolers. This is an economical design that has a short delivery period and is very popular (Jackmann 2007); however, its application is limited to smaller warehouses. In this design, cooler air is blown horizontally just underneath the ceiling, sweeping over and down through the stacks of the fruit placed on the floor, and then moves horizontally into the return vent to be recycled. Product loads must be stacked in ways that enable adequate cold air circulation, in order to remove the heat from the produce (Yahia and Elansari 2011).

Chilling Injury Related to Commercial Storage

Certain horticultural crops of temperate origin are susceptible to chilling injury (Bramlage and Meir 1990). Those temperate crops, in general, have lower threshold temperatures of <5 °C (41 °F). At these chilling temperatures of <5 °C, the tissues weaken because they are unable to carry on normal metabolic processes.

Various physiological and biochemical alterations and cellular dysfunctions occur in chilling-sensitive species in response to chilling stress (Raison and Orr 1990). When chilling stress is prolonged, these alterations and dysfunctions will lead to the development of a variety of chilling injury symptoms, such as surface lesions, internal discoloration, water soaking of the tissue, and failure to ripen normally (Saltveit and Morris 1990). Often, products that are chilled will still look sound when remaining in low temperatures. However, symptoms of chilling injury become evident shortly after they are moved to warmer temperatures. Fruits and vegetables that have been chilled may be particularly susceptible to decay. Weak pathogens such as *Alternaria* spp., which do not grow readily on healthy tissues, can attack tissues that have been weakened by low-temperature exposure. Both temperature and duration of exposure affect the development of chilling injury. Damage may occur in a short time if temperatures are considerably below the threshold level, but a product may be able to withstand temperatures a few degrees into the critical zone for a longer time before injury becomes irreversible. The effects of chilling are cumulative in some commodities. Low temperatures in transit, or even in the field shortly before harvest, add to the total effects of chilling that occur in cold storage. Treatments shown to alleviate chilling injury include intermittent warming; high- or low-temperature preconditioning; CA storage; pretreatments with ethylene, abscisic acid, methyl jasmonate, and other natural compounds; calcium or other chemical applications; hypobaric storage; waxing; film packaging; and genetic manipulation (Ryall and Lipton 1979; Wang 1994; Meir et al. 1997).

Transport Cooling

The transport cooling method in refrigerated ships and containers is used for products in areas with no cooling infrastructure. Temperate fruits are transported to diverse destinations by road, air, and water. Mechanical damage, especially due to bruising, during transport from the field to the packing facility is usually a major concern. Deterioration at this stage can also be caused by exposure to the sun or waiting to be transported or during transport if the product is not adequately covered. The warming up of the load or parts of the load of the fruit, especially due to restricted air flow, can increase fruit temperature very significantly and can also increase the accumulation of gases such as ethylene and CO_2, leading to significant deterioration. Excessive air flow through the load during transport can increase moisture loss and deterioration.

Centralized Packing Operations

Centralized packing in a packing house is usually more comfortable for workers than packaging in the field and, therefore, the packing efficiency is usually higher. Under this system, it is also possible to pack different grades of fruit and apply different treatments (such as washing, waxing, heat, chemicals).

Cleaning, Washing, and Sanitation

Washing eliminates soil and other materials, reduces fruit temperature, and can be the tool for the application of other treatments, such as chemicals used for sanitation. Chlorine, as liquid sodium hypochlorite or chlorine gas, at a concentration of 50–200 ppm, in water at a pH of 6.5–7.5, is a commonly used sanitation treatment for many fruits (Yahia and Elansari 2011). The washing water should be changed frequently depending on the fruit and rate of contamination, and chlorine activity.

Grading

Temperate fruits need to be graded by size to ensure that fruit of uniform size are packed together. The grading of fruits is done with different machines, either by weight or by dimensions. Traditional dimension sizers measure the fruit at two, three, and four contact points. Fruit sorting by rollers consists of passing the fruit on a bank of rollers which have different sized spaces between them. The fruit that fit between the rollers fall from the bank and are delivered into specific containers according to their size. Electronic sizers, which capture several video images of the fruit and calculate volume based on these images, are increasingly being used. Some of these graders are able to weigh each fruit 250 times in 0.1 s at their normal speed. The fruit are rotated as they pass under a video camera, which records multiple images. The pictures are then analyzed by specialized software to determine fruit diameter, shape, density, and color. These sorters are also able to determine shades of yellow in green apples and differentiate yellow and green apples from red ones. They also allow fruit grading based on blemish incidence (number, area, intensity, and position). According to these evaluations, each fruit is delivered to the appropriate outlet for the individual size/grade (Yahia and Elansari 2011).

Waxing

Some temperate fruits contain a superficial cuticle, which develops during fruit growth and ripening. Suberin, cutin, and waxes are its main components. The cuticle protects the fruit against dehydration, regulates gas exchange, and may also even protect against decay, as well as contribute to fruit appearance. However, it is removed or can be altered during fruit washing and some other handling operations, due to which there are greater chances of susceptibility of fruit to damage. Protective coatings have been applied to foods since the twelfth century, when, in China, paraffin was used to cover fruit as a method of preservation. Nowadays, the application of waxes to fruit is practiced commercially to overcome the negative effects of washing and some handling operations. Adequate waxing can, for example, reduce water loss, restrict gas exchange, and improve fruit appearance.

Drying

Droplets of water must be removed from fruits in order to reduce fruit decay, as water stimulates the growth of bacteria and fungi. In geographical areas with high temperatures and low RH, moisture evaporates quickly from the fruit. In contrast, in humid places, fruit needs to be dried. Several pieces of equipment are commonly used for this purpose. Generally, fruit is passed through a hot air tunnel, a treatment which quickly eliminates superficial water from the fruit. Metallic rollers covered with absorbent materials are also used to dry fruit after washing. While the fruit passes over a bank of these rollers, the washing water is removed. Water in the rollers is eliminated by a device that presses the absorbent material. A bank of brushes similar to those used for washing can also be used to dry fruit. Polyethylene or nylon bristles are suitable and it is common to use banks of 20 or more brushes in order to ensure proper drying.

Disease Control

Temperate fruits are prone to several diseases and, therefore, disease control treatments are important to reduce decay and deterioration. Diseases are one of the major causes of postharvest losses in temperate fruits. The most important decay-causing organisms are *Colletotrichum gloeosporioides* (causing anthracnosis), *Diplodia natalensis* (causing stem-end rot), *Ceratocystis paradoxa* (causing black rot), and *Penicillium*, as well as *Fusarium* (causing brown rot). Anthracnose is the major postharvest problem in several tropical fruits, and latent infection commonly occurs in green fruits before harvest (Yahia and Elansari 2011). Preharvest treatments and methods of disease control are important. These include the use of healthy seedlings, as well as proper field sanitation practices. Pesticides are still used to control decay before and after harvest, but physical measures such as postharvest heat treatments are effective and safer for consumers.

Packaging

Packaging is an important operation in the temperate fruit supply chain. Some fruits (such as grapes and strawberries) are commonly packed in the field, while others (such as apricots, apples, and pears) are commonly packed in central packing stations. Field packing can be very simple, requiring only packers and boxes, or more complex, with specially designed sheds and machines. Field packing has several advantages, as it reduces the time between harvest and cooling, reduces the possibility of manipulation of the product, and initial investments in this system are lower compared to packing in a centralized packing house. However, quality control and sorting into different grades during field packing are not easy and, in addition to that, it is difficult to carry out certain treatments (like washing, application of fungicides, waxing, heating, etc.).

Controlled Atmosphere (CA), Modified Atmosphere (MA), and Active Packaging (AP)

A CA is an atmosphere with a composition that is different from normal air and is strictly controlled (Yahia 2009). MA is an atmosphere with a different composition from normal air. AP is defined as "packaging in which subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system" (Robertson 2006).

MAs and CAs with lower levels of oxygen and/or higher levels of CO_2 than normal air can reduce rates of respiration and ethylene production, and reduce the action of ethylene, therefore delaying ripening and prolonging postharvest shelf life. Other advantages include decay control, alleviation of chilling injury, and reduction in losses of nutritional and health components (Yahia 2009).

Modified atmosphere packaging (MAP) involves the packaging of fruits in permeable materials and developing either passively (fruit respiration and gas permeating through the package) or semi-actively (by adding one or more gases to or eliminating them from the package). Low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS), polyvinylidene chloride (PVDC), and polyethylene terephthalate (PET) are the most common flexible materials (polymers) used in MAP (Yahia 2007). The preservation of avocados and loquat by MAP has been successfully achieved using polyethylene and PVC as packaging materials (Meir et al. 1997; Piga et al. 1996). Typically, the levels of O_2 and CO_2 in MAP are low and high, respectively. The packaging material must have specific permeability properties to ensure that O_2 and CO_2 concentrations reach levels that are optimal for reducing fruit metabolism without affecting its cellular functions (Yahia 2007). Low-permeability films generally cause off-flavors and the accumulation of fermentative metabolites in the fruit, while high-permeability films are not useful because they do not allow the development of adequate atmospheres. Microperforations are helpful to modify the permeability properties of low-permeability films, but other sophisticated means are available to modify the surrounding atmosphere for a specific fruit.

Besides fruit respiration, the elimination of O_2 can be achieved by several antioxidants, such as butylated hydroxyanisole, butylated hydroxytoluene α-tocopherol, β-carotene, tert-butylhydroquinone, and propyl gallate, which are generally incorporated into the films. Oxygen levels can also be diminished by introducing small sacs containing iron inside the package. CO_2 levels can be reduced or increased inside the package by using several compounds, such as iron oxide, calcium hydroxide, ferrous carbonate, metal halide, calcium oxide, activated charcoal, ascorbate, and sodium bicarbonate. Ethylene is commonly eliminated by using $KMnO_4$, which is incorporated into porous solids, such as activated alumina, vermiculite, and silica gel. Ethylene removal has also been achieved by using activated charcoal (alone or soaked with bromine), bentonite, tetrazine, and various crystalline aluminosilicates, such as zeolites.

Ripening

Hastening of Ripening

Maturity at harvest is the most important factor that determines storage life and quality of fruit. Immature fruits are more subject to shriveling and mechanical damage, and are of inferior quality when ripened. Overripe fruits are likely to become soft and mealy with insipid flavors soon after harvest. Fruits picked either too early or too late in the season are more susceptible to physiological disorders and have a shorter storage life than those picked at mid-season.

Some temperate fruits are ripened after arrival at their destination, especially climacteric fruits. These kinds of fruits (apple, apricot, pear, and peach) produce much larger quantities of ethylene in association with their ripening, and exposure to ethylene treatment will result in faster and more uniform ripening. Ethylene gas is commonly used for this process, and temperature is an important factor for the process of ripening. Ideal conditions for ripening are temperatures of 20–24 °C at high RH of 90–95%. Temperatures above 27 °C accelerate softening and may cause tissue discoloration, excessive decay, and off-flavors. Temperatures above 35 °C inhibit ethylene production and action, and, consequently, inhibit the process of ripening. Ripening is also impaired when fruits are exposed to chilling temperatures. The ripening rate can be manipulated by temperature management between 14 and 24 °C. Ethylene concentrations commonly used for fruit ripening range from 10 to 100 ppm. The removal of ethylene, using different agents such as potassium permanganate, is used to delay ripening in various fruits.

Control of Ripening and Senescence

Refrigeration is the most commonly used method to delay the ripening rate of fruits, although some of these fruits are susceptible to chilling injury. Fresh temperate fruits, especially those shipped to distant markets, need to be handled under refrigerated conditions. However, the cold chain may be non-existent for some fruits, especially in developing countries.

Several technologies have been developed to delay ripening in conjunction with refrigeration, including CA, MA, and heat treatments. 1-MCP, an inhibitor of ethylene action, has been shown to delay the postharvest ripening of several temperate fruits. The delay in ripening is extended if 1-MCP is used with other treatments, such as waxing. 1-MCP treatment delayed the onset of climacteric ethylene production and respiration in persimmon fruit and also significantly retarded the activities of pectin methyl esterase and polygalacturonase during ripening (Luo 2007). This gas reduced the respiration rate and completely suppressed PG activity (Jeong et al. 2003). 1-MCP has been regarded as an effective ripening inhibitor in apricot and strawberry (Shi et al. 2013; Villarreal et al. 2010).

Processing

Temperate fruits are processed into many different products using many different technologies; for example, apples and apricots are processed into different products such as jam, canned halves, pulps, or juices. These fruits are processed using traditional methods such as canning, concentration, fermentation, and dehydration, as well as newer methods, such as freeze-drying. The preliminary operations required are diverse and include washing, sorting, peeling, cutting, grinding, and blanching, among others. The raw materials need to be processed as soon as possible after harvest to avoid spoilage. Washing aims to eliminate any dirt stuck to the fruit before it enters the processing line, thus avoiding possible contamination of the raw material. It must be performed with clean water, possibly with added chlorine, either as sodium hypochlorite or chlorine gas. Sorting and selection is needed after washing to separate fruits which have defects or to grade them on the basis of ripeness, color, shape, and size, depending on the material and type of process to be performed. The fruits are usually peeled: the skin of the fruit is removed using physical devices such as knives or similar instruments, or heat or chemical methods. Peeling can improve the sensory quality of processed products, since the skin may contain pigments that are affected by thermal processing. Cutting to certain shapes and sizes is important to ensure even heat penetration during thermal processing and uniform drying. Products made from pieces of a similar size also have a better package appearance, since the packed material is more even in terms of its shape and weight. In the specific case of drying, cutting enhances the surface/volume ratio, which increases the efficiency of the process. High temperature is the preservation method used to produce pasteurized and canned products such as juices and pulps. Such thermal processes involve sterilization or pasteurization in jars, bottles, or other containers serving the same function. Sterilization can be applied to any product that has been peeled, cut, or has undergone some other preparation procedure, provided that it has been packaged in an appropriate container and sealed hermetically to prevent the penetration of microorganisms and oxygen. Sterilization prevents the survival of pathogenic or disease-causing organisms. Pasteurization is crucial to products such as pulps or juices (Yahia and Elansari 2011).

Quality control of processed products is very important. It must be a planned activity, with written specifications and standards for raw materials and other ingredients, the inspection of critical process control points, and, finally, examination of the entire system, including an inspection of the finished product (Yahia and Elansari 2011).

Conclusion

Temperate fruits have received attention throughout the world. Research findings have led to the development of many cultivars with highly appreciated characteristics, such as yield and postharvest behavior during long-term storage, in addition to

eating quality and adaptability to processing. The increased demand for fruits on the international markets implies continuous research and improvement of technologies to maintain quality and prolong the shelf life of produce.

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Postharvest Biology and Technology of Plum

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Introduction

Japanese plums (*Prunus salicina* Lindl.) and European plums (*Prunus domestica* L.) are famous nutritious stone fruits. These are mostly grown in the temperate or cool subtropical regions of the world. The plums of Japanese origin are generally consumed as fresh fruit, whereas European ones are famous for processing (Rieger 2006). The diversity of commercially available cultivars, extensive geographic distribution, and adaptability to diverse growing conditions make it an imperative and famous fruit around the world (Usenik et al. 2008). Plums are highly perishable fruit and have a short postharvest life that prevents their supply to distant global markets (Crisosto and Kader 2000). Due to rapid fruit softening, they are generally marketed within a narrow harvest window. Therefore, a glut of plums supply in the markets results in reduced price and profit for the growers (Plich and Michalczuk 1999).

Among various factors, respiration rate and ethylene production are most critical for the safe and prolonged storage of plum fruit (Singh and Khan 2010). The rate of fruit respiration normally depends upon different external and internal factors. The internal factors which affect the respiration rate include maturity stage and type of fruit, and whether the fruit are climacteric or non-climacteric. The respiration of the climacteric fruit is generally higher during the early stages of fruit development and, subsequently, decline with advanced maturity of the fruit. The increased respiration coincides with the ripening, reaches a peak, and decreases thereafter with the

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senescence of the fruit. Most of the plum cultivars exhibit climacteric rise of the respiration rate; however, some plum cultivars represent a suppressed climacteric rise (Abdi et al. 1998; Zuzunaga et al. 2001a). Plums are commercially harvested at a mature stage before ripening, so that they can endure the anticipated postharvest handling conditions (Singh and Khan 2010). After harvesting, plums rapidly lose their flesh firmness during ripening under ambient or low-temperature conditions. Due to prompt postharvest softening, the plum fruits are generally marketed merely under a short harvest period or based on the specific nature of cultivars (Plich and Michalczuk 1999).

During the ripening of plums, numerous changes occur in fruit that transition mature fruit from being sour and hard to having acceptable taste, texture, and flavor (Usenik et al. 2008; Díaz-Mula et al. 2009). However, at the same time, the lack of proper or uniform ripening, development of certain off-flavors, poor taste, astringency, and the development of different physiological disorders may significantly reduce the marketability of plums (Crisosto et al. 2007). Plums are highly perishable stone fruit and the rapid softening and ripening is responsible for their limited shelf life. The short shelf life poses a serious restraint for their proper storage and transportation. The rapid postharvest fruit softening and successive microbial infestations lead to significant economic losses during marketing. The storage of plum under low temperature is highly recommended for the extension of storage life and maintenance of quality (Wang 1993). However, the extended low-temperature storage of plums leads to various physiological disorders, such as chilling injury, internal browning, flesh reddening, mealiness, abnormal ripening, gel formation, reddish discoloration, flesh breakdown, increased decay, and loss of consumer acceptance (Guerra and Casquero 2008).

Ethylene (C_2H_4) is a natural fruit ripening hormone which modulates ripening at relatively small concentrations. Inhibition of the biosynthesis of ethylene is a possible pathway of fruit ripening retardation in plums (Singh and Khan 2010). There are numerous factors, either intrinsic or extrinsic, that enhance or impede C_2H_4 biosynthesis in plum fruit. The C_2H_4 action could be blocked by numerous chemicals, including certain unsaturated cyclic olefins. 1-Methylcyclopropene (1-MCP), polyamines (PAs), aminoethoxyvinylglycine (AVG), nitric oxide (NO), and salicylic acid (SA) have also been reported to inhibit or suppress C_2H_4 biosynthesis/production alone or in combination with cold, modified, and controlled atmosphere storage in plums (Khan and Singh 2009; Ozturk et al. 2012;Singh et al. 2009b; Davarynejad et al. 2015). The application of these chemicals can be used efficiently to prolong the storage life of plums with acceptable quality for the consumers.

The consumption of plums may be increased by offering uniformly ripened fruit with better cosmetic look, taste, flavor, and texture (Singh and Khan 2010). The in-depth understanding of the physiology of plums will facilitate us to extend their storage potential with maintained nutritional and sensory quality by adopting improved postharvest management protocols. This chapter will extend and complement the previous literature related to the postharvest physiology and technology of plums for enhancing their postharvest handling and management protocols.

Harvest Maturity

Harvest maturity plays a significant role in the determination of the anticipated eating quality and postharvest storage and/or shelf life potential of the stone fruits, including plum (Taylor et al. 1993b). It has been reported that both pre- and over-mature harvesting may significantly reduce the quality of plum fruit (Taylor et al. 1993b; Crisosto et al. 1995). The harvesting of plum fruit at early stages of maturity might prolong their shelf life and storability generally by precluding excessive firmness loss. However, it will also reduce the consumption of the early harvested plum fruit due to their poor quality compared to properly mature fruits (Abdi et al. 1997b; Guerra and Casquero 2009). Similarly, the less ripe fruit will lose water quickly and might be susceptible to certain physiological deteriorations, such as internal tissue breakdown (Crisosto et al. 1995). In contrast, there is an acceptance of the late-harvested plum fruit on a large scale, especially, as they are rich in flavor and taste, even though the postharvest shelf life of the said fruit is relatively short and they cannot be kept for long-term storage periods (Crisosto et al. 1995). As a result, it is critical for plum growers to determine the precise harvest maturity in order to obtain high quality fruit. Therefore, it is essential to systematically understand the characteristic maturity stage of the plum fruit that reliably reflect their anticipated quality (Abdi et al. 1997a). So, in this context, a large number of parameters have been suggested to thoroughly assess the characteristic harvest maturity stage of the plum fruit.

Numerous maturity parameters, including skin color, fruit firmness, fruit size, soluble solids concentration (SSC), titratable acidity (TA), and SSC/TA ratio are comprehensively used for the determination of the maturity stage of plum fruit at harvest (Robertson et al. 1991; Crisosto 1994). Among the considered parameters, fruit size may be one of the main indexes to specify the level of maturity of plum fruit. Nevertheless, fruit size alone cannot be used, as it is mainly influenced not only by the cultivar types investigated, but also by the crop load, prevailing climatic conditions, and the adopted cultural practices (Guerra and Casquero 2009). In stone fruits such as plums, fruit skin color is an important criteria used for the assessment of their maturity and ripening stage (Usenik et al. 2008), and an imperative factor for consumer acceptance (Daza et al. 2008). Nevertheless, in some of the plum varieties, the color of fruit skin develops at very early stages, when the fruits are still immature and have insufficient size and taste with poor flavor. Therefore, in the said case, the fruit skin color may possibly be of limited significance for the determination of proper harvest maturity (Usenik et al. 2008). Since the color of plum fruit skin in most of the cultivars changes to dark violet or full red before their true maturity, the measurement of firmness is suggested as a suitable alternate appropriate index of maturity (Crisosto and Kader 2000). The softening of fruit is also one of the critical factors for the estimation of the storage and market life potential of the plum (Usenik et al. 2008). However, presently, there is a lack of references regarding the use of firmness as a suitable maturity or ripening index, mainly for the European plum cultivars (Usenik et al. 2008). The concentrations of TA, SSC, and

SSC/TA ratio have been proposed as the most suitable alternate and most consistent maturity indices for consumer acceptance and evaluation of plums (Crisosto and Crisosto 2005). In plums, SSC has been associated with sweetness perception, aroma, and flavor (Crisosto et al. 2007; Díaz-Mula et al. 2008). In general, the plums with higher SSC (>12%) had greater consumer acceptance irrespective of their TA levels. It has been proposed that the use of SSC or TA as a maturity index alone is inadequate due to pronounced variations among the cultivars, production areas, and seasonal variability. On the other hand, the SSC/TA ratio has been found to be closely correlated with the quality of plum fruit compared to either TA or SSC alone (Casquero and Guerra 2009). In general, there is a lack of appropriate maturity index information based on the limited number of parameters used. Therefore, it remains very difficult to predict the optimum time for the picking of plum fruit.

Preharvest Factors Affecting Postharvest Handling of Plum

Soil, Climate, and Canopy Position

The soil and production site can influence the storage potential and related quality of plums. It was observed that 'Green Gage' European plums grown on soil with higher calcium (Ca) levels had better quality and fruit firmness both at harvest and during storage (Guerra and Casquero 2009). Climatic factors such as adequate light intensity and air temperature are the most important for optimum growth and yield (Kays 1999). High air temperature increases transpiration, which ultimately influences uptake and the metabolism of the applied nutrients to the plum plants (Kader 2002). Similarly, canopy light interception is also an important factor that affects the plant vegetative growth, fruit quality, and subsequent storage life potential (Taylor et al. 1993b).

Cultivar/Genotypic Effect

The tree genotypes (cultivars and/or rootstocks) play an imperative role in the determination of plum postharvest storage potential and fruit quality (Crisosto and Costa 2008). The different cultivars may lead to significant variations in the SSC and TA of the fruit (Crisosto et al. 1995). The growers also have the choice of choosing the desired cultivars prior to their planting of certain plum cultivars with improved quality and shelf life potential (Kader 2002). The cultivars with higher firmness may potentially have reduced softening along with extended storage potential (Guerra and Casquero 2009; Daza et al. 2012). It was observed that plum cv. 'Black Amber' revealed higher respiration and ethylene production as compared to 'Amber Jewel' and 'Angelino'. So, 'Black Amber' plum fruit would have shorter shelf life potential as compared to 'Amber Jewel' and 'Angelino' due to high climacteric peaks (Khan 2016).

Cultural Practices

Various cultural practices may also influence the postharvest life of plums. The 'Laetitia' plums shaded with ≤70% photosynthetic photon flux density (PPFD) during the preharvest stage were less mature at the time of harvest compared to fully exposed fruit. The practice of mulching may also influence the postharvest fruit quality of plums (Melgarejo et al. 2012). The preharvest deficit irrigation significantly increased fruit firmness and juiciness, along with higher SSC in 'Red Beaut' Japanese plums (Samperio et al. 2015). The application of GA_3 (50 mg L^{-1}) to 'Angelino' plums 14 weeks after anthesis as a fruit thinning agent increased the fruit size, firmness, color, SSC, and antioxidant activity (Erogul and Sen 2016).

Mineral Nutrition

Optimal quality and storage life performance may depend on the balanced availability of the mineral elements (Hewett 2006; Khan and Ali 2018). Potassium (K) and nitrogen (N) are important macronutrients required in large quantities by plants for their proper growth and development (Cuquel et al. 2011). Excessive N application increases the vegetative growth and delays the maturity of several stone fruits, including plums (Daane et al. 1995). On the other hand, N deficiency leads to the small-sized fruits and poor flavor (Daane et al. 1995). Similarly, optimum K improves the plum fruit quality by increasing the sugars and organic acids (Crisosto and Costa 2008). Ca is also important for the fruit trees. Ca plays an imperative part in delaying the senescence of fruit (Serrano et al. 2004). The increased storage life with maintained quality has been reported for various plum cultivars in response to the application of Ca (Kirmani et al. 2015), boron (Plich and Wójcik 2002), magnesium (Alcaraz-Lopez et al. 2003), titanium (Alcaraz-Lopez et al. 2003), and N or K (Cuquel et al. 2011).

Irrigation

Water is important for increased yield and premium quality of fruits, including plums. Irrigation enhances the soil water availability, plant water status, and fruit quality (Berman and DeJong 1996; Naor et al. 1999, 2001). The deficit irrigation applied at the preharvest stage resulted in significantly higher fruit firmness and juiciness, along with an increase in the SSC in 'Red Beaut' Japanese plums (Samperio et al. 2015).

Preharvest Application of Different Chemicals

Preharvest application of various mineral elements and ethylene binding compounds have also been reported to improve postharvest quality and to extend the storage potential of plum fruit (Table 1; Alcaraz-Lopez et al. 2003; Zuzunaga et al. 2001a; Khan et al. 2007, 2008; Khan and Singh 2008b; Ozturk et al. 2015; Harman and Sen 2016).

Fruit Ripening

The consumer acceptability and postharvest market life of the plum fruit largely depend upon uniform and proper ripening. During the ripening of plum fruit, numerous physiological changes such as the production of ethylene, respiration rate, softening, carbohydrates, organic acids metabolism, external and internal fruit color, aroma volatile production, antioxidants, and health-promoting bioactive compounds take place (Usenik et al. 2008; Díaz-Mula et al. 2009; Singh et al. 2009a). However, extensive variations can be witnessed in these attributes based on cultivars, productions areas, climatic conditions, and maturity stage at harvest (Crisosto and Kader 2000).

Physiological and Biochemical Changes During Fruit Ripening

Most of the plum cultivars have been characterized as climacteric. However, it is not a consistent behavior across all cultivars (Abdi et al. 1997b). Therefore, plum fruit can be categorized as climacteric, such as ‘Amber Jewel’, ‘Black Amber’, ‘Beauty’, ‘Gulf Ruby’, ‘Black Star’, ‘Tegan’, and ‘Santa Rosa’, and suppressed climacteric types, like ‘Angeleno’, ‘Golden Japan’, ‘Ruby Red’, ‘Shiro’, and ‘Songold’ (Guerra and Casquero 2008). In climacteric plum cultivars, the ripening is considered with a pronounced increase in both respiration rate and ethylene production. On the other hand, ethylene production in the suppressed climacteric plum cultivars is not sufficient to prompt an increase ethylene production and respiration (Abdi et al. 1997b). However, the cultivars with suppressed climacteric behavior have relatively longer storage life compared to climacteric plums, as the potential postharvest storage life of the fresh fruit is largely dependent on the ethylene production and respiration rate (Abdi et al. 1998; Khan and Singh 2007a; Guerra and Casquero 2008; Usenik et al. 2008; Díaz-Mula et al. 2009).

Table 1 Effects of different preharvest chemical sprays on the quality and postharvest physiology of plums

Chemicals	Cultivars	Time	Concentrations	Storage conditions	Inferences	References
AVG	'Black Amber'	2 weeks before harvest	100 and 200 mg L^{-1}	28 days at 0 °C with 90% RH	Decreased fruit firmness, TPC, and total antioxidants. Increased SSC with increased storage up to 21 days	Ozturk et al. (2012)
AVG	'Black Amber'	2 weeks before harvest	100 mg L^{-1}	28 days at 0 °C	Retarded color changes with increased firmness and TPC	Ozturk et al. (2013)
AVG	'Black Beauty'	2 weeks before harvest	100 and 200 mg L^{-1}	28 days at 0 °C with 90% RH	Reduced weight loss, color changes, and showed higher TPC and antioxidants	Kucuker et al. (2015)
AVG	'Black Beauty', 'Black Amber', 'Friar'	Sprayed at full bloom	100 and 200 mg L^{-1}	–	Reduced SSC, TPC, and total antioxidants. Increased fruit firmness, ripening index, and acidity	Ozturk et al. (2015)
B	'Stanley', 'Dąbrowicka Prune'	Five sprays, first at petal fall and then after 10 days interval	0.67 kg ha^{-1}	42 days at 0.5 °C + 3 days simulated shelf life	Reduced weight loss and increased firmness	Plich and Wójcik (2002)
Ca	'Stanley', 'Dąbrowicka Prune'	Five sprays, first at petal fall and then after 10 days interval	1.8 kg ha^{-1}	42 days at −0.5 °C with 90–95% RH	Reduced weight loss and increased firmness	Plich and Wójcik (2002)
Ca	'Victoria', 'Jubileum', 'Opal'	2 weeks before harvest	10 L ha^{-1}	14 days at 2 °C + 2 days at 20 °C	Inhibited *Monilinia* spp. induced postharvest decay	Vangdal and Børve (2002)
Ca	'Red Beaut'	First spray 30 days after harvest, second at 10 days after anthesis, third at fully developed leaves stage	0.10 mM	5 days at 22 ± 3 °C with 90–95% RH	Increased fruit size, resistance to penetration or compression damage, and reduced weight loss	Alcaraz-Lopez et al. (2003)

(continued)

Table 1 (continued)

Chemicals	Cultivars	Time	Concentrations	Storage conditions	Inferences	References
Ca	'Mallard', 'Victoria'	6, 4, and 2 weeks before harvest	500 g per 100 L	21 days at 4 °C	Reduced decay and delayed ripening	Vangdal et al. (2007)
Ca	'Santa Rosa'	20 and 10 before harvest	60 ppm	10 days at 2 °C + 2 days at 20 °C	Increased SSC, TA, AA, and juice content	Kirmani et al. (2015)
Ethrel	'Kelsey'	1st and 9th July of the year	500 ppm	7 days at 22 ± 2 °C	Maintained physical and biochemical fruit quality	Farag and Attia (2016)
GA_3	'Santa Rosa'	20 and 10 days before harvest	60 ppm	10 days at 2 °C + 2 days at 20 °C	Increased SSC, TA, AA, and juice content	Kirmani et al. (2015)
GA_3	'Obilnaja', 'Black Star'	At color change time	50 ppm	20 days at 2 °C and 90% RH	Increased fruit size, weight, flesh firmness, and SSC	Harman and Sen (2016)
GA_3	'Angelino'	10 weeks post full bloom	50 ppm	90 days at 0 °C + 2 day on shelf	Decreased weight loss, increased firmness with higher TPC, antioxidants, TSS, and TA	Erogul and Sen (2016)
K	'Reubennel'	Three splits as first, full bloom; second, after thinning; third, after harvest	110 kg ha^{-1}/year	37 days at 0 ± 0.5 °C	Increased firmness, SSC, and TA	Cuquel et al. (2011)
Lisophos	'Kelsey'	1st and 9th July	400 ppm	7 days at 22 ± 2 °C	Increased firmness, reduced weight loss and electrolyte leakage, and enhanced sugars, SSC, TA, and carotenoids	Farag and Attia (2016)
MJ	'Black Amber'	2 weeks before harvest	100 mg L^{-1}	28 days at 0 °C	Increased firmness and TPC	Ozturk et al. (2013)

MJ	'Fortune'	2 weeks before harvest	1120 mg L^{-1}	28 days at 0 °C	Increased total TPC, antioxidant, and chlorogenic acid	Karaman et al. (2013)
MJ	'Black Splendor', 'Royal Rosa'	63, 77, and 98 days after full bloom	0.5 mM	50 days at 2 °C + 1 day at 20 °C	Delayed ripening and ethylene production, and increased TPC, POD, CAT, and APX activities	Zapata et al. (2014)
MJ	'Black Beauty', Black Amber', 'Fortune'	2 weeks before harvest	2240 mg L^{-1}	28 days at 0 ± 0.5 °C with 90 ± 5% RH	Delayed weight and firmness loss with inhibited ripening	Kucuker and Ozturk (2014)
Mg	'Red Beaut'	First at 30 days after harvest, second at 10 days after anthesis, third at fully developed leaves stage	0.10 mM	5 days at 22 ± 3 °C with 90–95% RH	Increased fruit size, resistance to penetration or compression damage, and reduced weight loss	Alcaraz-Lopez et al. (2003)
N	'Reubennel'	Three splits as first at full bloom, second after thinning, third after harvest	40 kg ha^{-1} $year^{-1}$	37 days at 0 ± 0.5 °C	Increased firmness, SSC, and TA	Cuquel et al. (2011)
NAA	'Santa Rosa'	20 and 10 days before harvest	60 ppm	10 days at 2 °C + 2 days at 20 °C	Increased TSS, TA, AA, and juice contents	Kirmani et al. (2015)
Oleic acid	'Kelsey'	1st and 9th July	400 ppm	7 days at 22 ± 2 °C	Increased firmness, reduced weight loss and electrolyte leakage, and enhanced, sugars, SSC, TA, and carotenoids	Farag and Attia (2016)

(continued)

Table 1 (continued)

Chemicals	Cultivars	Time	Concentrations	Storage conditions	Inferences	References
PUT	'Angelino'	1 week before commercial harvest	1 mM	42 days at 0 ± 1 °C with 90 ± 5% RH	Delayed ethylene production, ripening with higher firmness, SSC, TA, carotenoids, antioxidants, and ascorbic acid	Khan and Singh (2008a)
PUT	'Angelino'	1 week before commercial harvest	2 mM	42 days at 0 ± 1 °C with 90 ± 5% RH	Delayed ethylene production, reduced respiration rate, inhibited ripening, showed higher firmness, SSC, TA, carotenoids, antioxidants, and ascorbic acid	Khan and Singh (2008b)
PUT	'Angelino', 'Black Amber', 'Amber Jewel'	1 week before commercial harvest	2 mM	13 days at 20 ± 1 °C with 65 ± 5% RH	Delayed ethylene production, reduced respiration rate, inhibited ripening, reduced ACS, ACO, and ACC activities, showed higher firmness, SSC, TA, carotenoids, antioxidants, and ascorbic acid	Khan and Singh (2010)
Ti	'Red Beaut'	Three applications as first at 30 days after harvest, second 10 days after anthesis, third at fully developed leaves stage	0.04 mM	5 days at 22 ± 3 °C with 90–95% RH	Increased fruit size, resistance to penetration or compression damage, and reduced weight loss	Alcaraz-Lopez et al. (2003)

Respiration and Ethylene Production Rates

Plums have been classified as a climacteric fruit with a distinct ethylene production increase phase and production of CO_2 (Abdi et al. 1997b). The O_2 consumption or CO_2 production rates increase from the minimum levels to higher peaks and decline subsequently due to overripening of the plum fruit (Khan et al. 2009). The behavior of climacteric rise is also affected by the nature of cultivars, maturity stages, preharvest production factors, storage conditions, atmospheric compositions, certain postharvest treatments, mechanical injuries, and the occurrence of decay (Khan and Singh 2007a, b; Khan et al. 2007, 2009).

The ripening of plum fruit is efficiently regulated by the endogenous biosynthesis of ethylene. It has been observed that, during the ripening of fruit, the biosynthesis of ethylene starts with methionine conversion to S-adenosyl methionine. ACS and ACO are the two major enzymes involved in the biosynthesis of ethylene. Both ACS and ACO enzymes have been reported to convert S-adenosyl methionine to malonyl 1-aminocyclopropane-1-carboxylic acid (MACC), ACC, and ethylene, respectively (Khan and Singh 2007b; Khan et al. 2007, 2008; Larrigaudière et al. 2009). Both exogenously applied and endogenous ethylene production significantly influences external fruit appearance, flavor, texture, and nutritive values of plums (Larrigaudière et al. 2009; Manganaris et al. 2008a). The concentration of ethylene (10–1000 μL L^{-1}) is used commercially to stimulate climacteric fruit ripening, including among plums (Saltveit 1999). The levels of endogenous ethylene generation during the suppressed climacteric behavior ripening cultivars ('Angelino' or 'Amber Jewel') and climacteric cultivars such as 'Tegan Blue' ranged from 0.03 to 1.8 μmol kg^{-1} h^{-1}, respectively (Khan and Singh 2007b; Khan et al. 2009). The action of ethylene can be inhibited by different chemicals, such as AVG, 1-MCP, NO, and PAs (Khan et al. 2007; Khan and Singh 2008b; Ozturk et al. 2012; Sharma and Sharma 2016). The probable molecular mechanisms associated with the ripening of plum fruit have been investigated for a better understanding of the factors involved in the differences in ripening rates among various cultivars (Abdi et al. 1997a; El-Sharkawy et al. 2007, 2008, 2009).

Fruit Softening

The firmness of flesh is a leading factor which determines the postharvest storage potential of plums (Usenik et al. 2008). Plum harvesting at higher flesh firmness safeguards the maintenance of fruit quality during transportation and marketing. Higher flesh firmness also ensures minimum postharvest decay and bruise injuries during the standard adopted postharvest operations (Crisosto et al. 2007). Like various other climacteric fruits, the softening of plums occurs due to the cell loosening upon disassembly and degradation of the cell walls. The level of hemicelluloses and pectins in cell walls endure depolymerization and solubilization, which lead to the

structural and various compositional changes in the carbohydrate units of the cell walls (Fischer and Bennett 1991). The depolymerization and solubilization take place due to cell wall hydrolyzing enzyme activities (Khan and Singh 2008b; Manganaris et al. 2008b). Various enzymes are related to the softening of fruits, such as endopolygalacturonase (Endo-PG), exo-polygalacturonase (Exo-PG), endo-1,4-β-D-glucanase (EGase), and pectin esterase (PE) (Khan and Singh 2009; Fischer and Bennett 1991). Exogenous applications of different chemicals such as AVG, MJ, 1-MCP, and PAs has been found to appropriately delay the softening of plum fruit during cold storage and ripening at ambient temperature (Khan and Singh 2007a, b; Khan et al. 2007). The decreased plum softening with the application of AVG, MJ, 1-MCP, or PAs may be accredited to the reduction of ethylene biosynthesis and production. Therefore, suppressed production of ethylene during the ripening of fruit resulted in reduced softening due to the retardation of activities of various fruit softening enzymes (Khan and Singh 2007b, 2009; Singh and Khan 2010).

Carbohydrates and Organic Acids

Plum fruit are known as a rich source of organic acids and sugars. During fruit ripening, the concentrations of sucrose increase and exceed the amount of reducing sugars. It has also been observed that various cultivars may also differ in the comparative amounts of glucose, sorbitol, fructose, and sucrose (Usenik et al. 2008; Singh and Singh 2008). During the ripening of early- ('Black Amber'), mid- ('Amber Jewel'), and late-maturing plum fruits ('Angeleno'), the major sugar was fructose, followed by glucose, sucrose, and sorbitol (Singh and Singh 2008). The SSC/TA ratio is the most consistent attribute for plums ripening because, during the fruit ripening, the levels of sweetness progressively increase with an increase in the storage period (Casquero and Guerra 2009; Khan and Singh 2007a). Malic acid was found to be the major acid in the share of total organic acids in plums (Usenik et al. 2008; Singh et al. 2009a). Nevertheless, in some other plum cultivars, a minor quantity of tartaric and quinic acids has also been reported (Meredith et al. 1992). The concentration of malic acid is known as the major contributor to organic acids decreases at the fully ripe stage; therefore, increasing the SSC/TA ratio (Crisosto and Kader 2000).

Fruit Color Development

Plum skin color is an imperative external criteria for the quality of fruit and the leading factor in making purchasing decisions. The plum fruit color is usually due to the concentrations of carotenoids and anthocyanins. Peonidin-3-rutinoside and cyanidine-3-rutinoside are the main anthocyanins in plums. It has been found that, during fruit maturation and ripening, the levels of anthocyanins and carotenoids

increase in both skin and flesh tissues of plums (Usenik et al. 2008). Change of the ground color is also a reliable index of ripeness in some of the plum cultivars (Daza et al. 2008). The color of the fruit is contributed by various pigments, such as carotenoids and anthocyanins in the skin or flesh of the plums. After maturation and during ripening of the plum fruit, color normally changes from green to reddish purple or yellow, depending upon the cultivars. Normally, during fruit ripening, the values of the coloring parameters (L^*, a^*, and b^*) in the fruit skin and flesh of the plums decrease based on the cultivars, maturity stages, pre- or postharvest chemical treatments, and storage or ripening conditions (Usenik et al. 2008; Guerra and Casquero 2008; Casquero and Guerra 2009; Khan et al. 2007, 2009). Therefore, the color of fruit is an important feature in the determination of its marketability and acceptance of the consumers (Usenik et al. 2008; Daza et al. 2008, 2012).

Phytochemicals

Plum fruit are an excellent source of natural bioactive compounds, such as phenolics, anthocyanins, and vitamins. The fruit are also a rich source of enzymatic antioxidants, such as catalase (CAT), superoxide dismutase (SOD), and peroxidase (POD) (Usenik et al. 2008; Kim et al. 2003b; Halliwell 1999; Vizzotto et al. 2006). The antioxidant activities are related to the free radicals scavenging activities, which neutralize the ROS (Díaz-Mula et al. 2009). Similarly, higher levels of phenolic compounds are found in different cultivars of plum. The derivatives of hydroxycinnamic acid, including neoclorogenic acids and chlorogenic acids, are the leading phenolics found in plums (Raynal et al. 1989; Tomás-Barberán et al. 2001). The concentration of ascorbic acid normally ranges from 3 to 10 mg 100^{-1} g FW, whereas carotenoids may range from 70 to 260 μg 100^{-1} g, depending upon the nature of various cultivars (Kim et al. 2003a). The consumption of plums in our daily food can be a very good source of numerous health-promoting bioactive compounds (Kim et al. 2003b). Variations may exist in the levels of phytochemicals and nutraceuticals among various plum varieties (Díaz-Mula et al. 2009; Gil et al. 2002; Vasantha-Rupasinghe et al. 2006; Kim et al. 2003a; Medina-Meza and Barbosa-Cánovas 2015).

Aroma Volatiles Compounds

The aroma volatiles production in plum fruit differs among the cultivars. The Japanese plums have been known to produce very low levels of aroma volatiles (Gomez and Ledbetter 1994). The aroma volatiles composition generally changes both qualitatively and quantitatively during maturation and fruit ripening (Lavilla et al. 2001). In plums, alcohols, aldehydes, esters, and ketones are responsible for the development of aromatic volatiles (Gomez et al. 1993). At the preclimacteric or mature stage, the concentration of aroma volatiles remains low and progressively

increases with the ripening of the fruit (Tromp 2005). Several factors such as storage temperatures, increased respiration rate, and higher gas resistance diffusion can enhance the production of aroma volatiles. In contrast, comparatively higher O_2 concentrations and higher SSC lead to increased development of the off-flavor related to the accumulation of ethanol (Ke and Kader 1992). A large number of the compounds have been found to be related to the development of aroma volatiles during the ripening of plum fruit. Among the said volatiles, aldehydes, alcohols, terpenes, and esters may be distinguished between unripe and ripe plum fruit. About 130 volatile compounds, including one phenol, two acids, three terpenes, four heterocycles, eight ketones, eight lactones, 11 aldehydes, 25 hydrocarbons, and 62 esters have been identified from the extract of 'Mirabelles' plums (Etievant et al. 1997). On the other hand, Krammer et al. (1991) reported 31 different volatile compounds in the flesh of yellow 'syriaca' plums. Recently, Cuevas et al. (2016) reported 25 different volatiles in plum cvs. 'Laetitia', 'Sapphire', 'Primetime', 'Songold', 'Showtime', and 'Souvenir'.

Modulation of Fruit Ripening with Different Postharvest Strategies

Ethylene

Ethylene has been found to be involved in the ripening of plums. The ethylene biosynthesis and/or action inhibition provides an effective pathway of fruit ripening retardation (Singh and Khan 2010). Different treatments, including the exogenous applications of AVG, 1-MCP, NO, and PAs, were found to be effective in delaying the fruit ripening in different plum cultivars (Khan and Singh 2009, 2008c; Singh et al. 2009b). The exogenous application of ethylene-inducing chemicals or ethylene accelerates the ripening of plum fruit having reduced shelf and storage life potential with increased development of various physiological disorders (Palou et al. 2003; Dong et al. 2001; Manganaris et al. 2008c).

Auxins

Besides ethylene, auxins can also regulate the ripening of plum fruit (El-Sharkawy et al. 2016). It is now clear that the levels of auxins substantially influence the steps involved in the beginning and progression of the ripening or softening of plums (Table 2). The autonomous regulation of numerous ethylene-dependent components and the subsequent disassembly of the cell- wall-related transcripts are mediated by the endogenous concentrations of auxins in plums (El-Sharkawy et al. 2016).

Methyl Jasmonate

Jasmonic acid (JA) or its methyl ester, i.e., MJ, are natural plant growth regulators. MJ is involved in different higher plants responses, such as growth, cell division (Kondo and Fukuda 2001; Khan et al. 2017), and fruit ripening (Fan et al. 1998; Khan and Singh 2007a). JA or MJ are synthesized from the 13-hydroperoxy-linolenic acid through allenes oxidase cyclase and allenes oxidase synthase mediated pathways. The biosynthesis of MJ starts with linolenic acid, which is eventually changed into MJ or other different conjugates via different enzymatic catalyzed phases (Creelman and Mullet 1997). MJ concentrations have been found to change during the developmental phases of fruit. MJ stimulates the ripening of various climacteric fruits through the induction of ethylene biosynthesis (Fan et al. 1998). Exogenous applications of MJ also trigger the ripening process of different climacteric fruits by increasing the production of ethylene, including plums (Fan et al. 1997; Kondo et al. 2000). Therefore, exogenous application of MJ stimulates the ripening of different climacteric fruits by enhancing the biosynthesis of ethylene (Fan et al. 1998). MJ has also been reported to stimulate or induce the production of ethylene through the stimulation of activities of ACO and ACS and the increase in ACC production (Table 2). MJ also increases the softening and activities of softening-related enzymes during the ripening of plums. The preharvest MJ sprays applied at 2 weeks before harvest resulted in delayed weight and firmness loss, with inhibited fruit ripening (Ozturk et al. 2013; Kucuker and Ozturk 2014). Similarly, MJ application to the 'Black Splendor' and Royal Rosa' cultivars led to delayed ethylene production, reduced respiration rate, higher phenolic contents, and total antioxidants, ascorbate peroxidase (APX), peroxidase (POD), and catalase (CAT) enzymes activities for 50 days during cold storage at 2 °C and 1 day at 20 °C (Table 2; Zapata et al. 2014).

1-Methylcyclopropene

1-Methylcyclopropene (1-MCP) is an ethylene antagonistic compound which affects the production and action of ethylene, subsequently delaying ripening and enhancing the storage life of different non-climacteric and climacteric fruits (Watkins 2006). At both low- and ambient-temperature environments, 1-MCP impedes autocatalytic ethylene biosynthesis or production and permanently binds with the receptors of ethylene and converts ACC to MACC (Larrigaudière et al. 2009; Dong et al. 2001) and/or glutamylamino derivative (Abdi et al. 1998), in spite of the ethylene in various cultivars of plum. The blockage of ethylene production eventually reduces fruit ripening and increases the postharvest life of the plum fruit. Similarly, postharvest 1-MCP application has been found to decrease and impede the production of ethylene (Khan and Singh 2009) and the respiration rate (Khan et al. 2009). The reduced climacteric changes ultimately lead to delayed skin or

flesh color development, rate of fruit softening (Khan and Singh 2008b), total antioxidants, ascorbic acid, and carotenoids (Khan et al. 2009). Moreover, it also reduces the development of chilling injury (CI) during cold storage (Menniti et al. 2006; Manganaris et al. 2008c). The application of 1-MCP to 'Autumn Giant' and 'Black Beauty' plums reduced softening, respiration rate, ethylene production, and flesh browning, with higher firmness and biochemical quality (Erkan and Eski 2012). The application of 1-MCP also delays the ripening of fruit and prolongs the postharvest shelf life of the plums by reducing ACO and ACS activities and Endo-PG, EGase, Exo-PG, and PE enzymes related to the ripening and softening of plums, respectively (Table 2; Khan and Singh 2007b; Khan and Singh 2009). The impact of 1-MCP on the fruit quality and shelf life of the 'Songold' plum has been reported by Velardo-Micharet et al. (2017). 1-MCP application maintained fruit sensory attributes along with biochemical characteristics throughout the storage period of 50 days at 0 °C. Moreover, the combined application of CA storage and 1-MCP reduced the incidence of CI, oxidative stress, lipid peroxidation, and membrane leakage in 'Black Amber' plum for 8 weeks at 0 °C (Table 2; Singh and Singh 2012). The application of 1-MCP reduced the activities of POX enzyme and inhibited the synthesis of MACC in 'Larry Ann' plum after 14 days of storage at 0 °C. Earlier, 1-MCP application has been reported to delay ethylene production, reduce weight loss, loss of pulp firmness, and ripening index in 'President' plum throughout 4 weeks of cold storage at 1 °C under 90% RH, followed by 7 days at 20 °C (Valero et al. 2003). In 'Fortune' and 'Angeleno' plums, 1-MCP fumigation in combination with CA storage maintained fruit firmness and reduced brown rot and internal breakdown of the fruit after 80 days of storage at 0 °C with 3 days during shelf period at 20 °C for 11 days (Menniti et al. 2006). The 1-MCP-treated 'Tegan Blue' plum fruit showed reduced ACS and ACO enzymes synthesis that ultimately reduced the ripening index and extended the cold storage life at 0–1 °C for up to 6 weeks (Table 2; Khan and Singh 2009).

Polyamines

Endogenous PAs levels have been shown to change during the ripening process, depending upon the cultivars and maturity of the fruit at the time of harvest (Zuzunaga et al. 2001a). The endogenous concentrations of PAs reduced during the ripening of plum fruit and concurred with the increased ethylene biosynthesis (Zuzunaga et al. 2001b). PAs generally delay the senescence process by stabilizing the cell membranes and impeding the activities of fruit softening enzymes (Endo-PG, Exo-PG, EGase, and PE). Hence, exogenous application of PAs has been found to be an effective method to delay plum fruit ripening (Singh and Khan 2010). PAs application has been found to be antisenescent and their exogenous treatments have also been reported to retard softening, delay ripening, inhibit ethylene production, reduce respiration, and delay color changes in various cultivars of plums (Khan et al. 2007, 2008; Khan and Singh 2008a). The PAs application also inhibited

Table 2 Effects of postharvest application of various chemicals on the storage potential and shelf life of different fruits

Chemicals	Cultivars	Concentrations	Storage conditions	Inferences	References
Ca	'Black Star'	1 mM	28 days at 2 °C with 90% RH	Delayed ripening, increased conjugated form of PUT with maintained firmness	Valero et al. (2002)
ClO_2	'Black Diamond'	40 mg L^{-1} + 100 W ultrasound	60 days at4 °C	Reduced ethylene production, respiration rate with higher total flavonoids, sugars, ascorbic acid, TA, and sensory quality	Chen and Zhu (2011)
MJ	'Black Splendor', 'Royal Rosa'	0.5 mM	9 days at 20 °C, 50 days at 2 °C + 1 day at 20 °C	Delayed ethylene production and reduced respiration rate. Maintained higher phenolic contents, total antioxidants, APX, POD, and CAT activities	Zapata et al. (2014)
NO	'Amber Jewel'	10 µL L^{-1}	42 days at 0 °C with 90% RH + 5 days at 21 ± 1 °C	Reduced CI, flesh browning, translucency	Singh et al. (2009b)
NO	'Santa Rosa'	0.50 mM	30 days at 2 °C with 90% RH + 3 days at 20 °C	Reduced MDA contents, PAL and PMC enzymes activities, CI, and internal browning	Sharma and Sharma (2014)
OA	'Damili'	5 mM	20 days at 2 °C with 90% RH + 12 days at 25 °C	Reduced ethylene production, PME, PG activities, delayed softening, and inhibited flesh reddening	Wu et al. (2011)
PUT	'Angelino'	1 or 2 mM	42 days at 0 ± 1 °C with 90 ± 5% RH	Delayed ethylene production, reduced respiration rate, reduced ACS, ACO, ACC, Exo-PG, Endo-PG, PE, and EGase activities, with higher firmness, SSC, TA, antioxidants, and ascorbic acid	Khan et al. (2007)
PUT	'Angelino'	1 mM	42 days at 0 ± 1 °C with 90 ± 5% RH	Delayed ethylene production, ripening, with maintained firmness, SSC, TA, antioxidants, and ascorbic acid	Khan and Singh (2008a)
PUT	'Angelino'	2 mM	42 days at 0 ± 1 °C with 90 ± 5% RH	Delayed ethylene production, reduced respiration rate, inhibited ripening, showed higher firmness, SSC, TA, antioxidants, and ascorbic acid	Khan and Singh (2008b)

(continued)

Table 2 (continued)

Chemicals	Cultivars	Concentrations	Storage conditions	Inferences	References
PUT	'Angelino', 'Black Amber', 'Amber Jewel'	2 mM	13 days at 20 ± 1 °C with 65 ± 5% RH	Reduced ethylene production, respiration rate, with reduced ACS, ACO, and ACC activities, showed higher firmness, SSC, TA, carotenoids, antioxidants, and ascorbic acid	Khan and Singh (2010)
PUT	'Santa Rosa'	4 mM	25 days at 4 °C with 90% RH	Increased maturity index, SSC, while decreased firmness, TA, ascorbic acid, phenolic contents, and antioxidants	Davarynejad et al. (2015)
SA	'Santa Rosa'	2 mM	21 days at 2 °C with 90 ± 5% RH + 6 days at 20 ± 1 °C with 90 ± 5% RH	SA-treated fruit exhibited the lowest MDA content, ethylene production, PAL and PME activities, and electrolyte leakage	Sharma and Sharma (2016)
SA	'Santa Rosa'	4 mM	25 days at 4 °C with 90% RH	Increased maturity index, SSC, while decreased firmness, TA, ascorbic acid, phenolic contents, and antioxidants	Davarynejad et al. (2015)
SA	'Qingnai'	1.5 mM	60 days at 1 °C with 90% RH	Reduced CI, membrane leakage, MDA content, delayed PPO and POD enzymes activities	Luo et al. (2011)
1-MCP	'President'	0.3 and 0.5 μL L^{-1}	42 days at 1 °C with RH 90% + 7 days on shelf at 20 °C	Delayed ethylene production, reduced weight loss, loss in pulp firmness and ripening index	Valero et al. (2003)
1-MCP	'Fortune', 'Angeleno'	300 and 500 nL L^{-1}	60 days at 0 °C with 90% RH ('Fortune') and 60 ('Angeleno') days in air at 0 °C, 80 days in CA (1.8% O_2 + 2.5% CO_2) + 11 ('Fortune') and 14 ('Angelino') days on shelf at 20 °C	Delayed loss of firmness, reduced brown rot and internal breakdown	Menniti et al. (2006)

1-MCP	'Angeleno'	300 or 500 nL L^{-1}	80 days at 0 °C under CA + 14 days at 20 °C	Reduced fruit rot and internal breakdown	Menniti et al. (2006)
1-MCP	'Tegan Blue'	2 μL L^{-1}	10 days at 20 ± 1 °C	Delayed ethylene production, ACS, ACO, ACC, PE, EGase, Exo-PG, and Endo-PG activities	Khan and Singh (2007b)
1-MCP	'Joanna Red'	1000 or 10,000 ng kg^{-1}	10 days at 5 °C with 90% RH + shelf life at 23 °C	Delayed ripening and ameliorated CI	Manganaris et al. (2008a)
1-MCP	'Qingnai'	500 nL L^{-1}	21 days at 20 °C with 90% RH	Delayed softening, reduced ethylene production, respiration rate with higher fruit firmness, chlorophyll content, TA, lower chlorophyllase, PME, and PG activities	Luo et al. (2009)
1-MCP	'Larry Ann'	625 nL L^{-1}	14 days at 0 and 20 °C	Inhibited MACC synthesis and reduced POD enzyme activity	Larrigaudière et al. (2009)
1-MCP	'Tegan Blue'	1.0 or 2.0 μL L^{-1}	42 days at 0–1 °C with 90 ± 5% RH	Exhibited higher fruit firmness along with reduced Exo-PG, Endo-PG, ACS, and ACO enzymes activities	Khan and Singh (2009)
1-MCP	'Royal Zee', 'Linda Rosa', 'Friar', and 'Angeleno'	0.40 μL L^{-1}	50 days at 0 °C 90% RH.	Reduced ethylene production, CI, and translucency, showed higher firmness and biochemical quality	Candan et al. (2011)
1-MCP	'Black Amber'	0.6 μL L^{-1}	42 days at 0 °C under CA-1 (1% O_2 + 3% CO_2), CA-2 (2.5% O_2 + 3% CO_2), and MAP (10% O_2 + 3.8% CO_2)	CA combined with 1-MCP reduced oxidative stress, lipid peroxidation, glutathione level, and CI compared to MAP	Singh and Singh (2012)
1-MCP	'Black Amber'	0.6 μL L^{-1}	56 days at 0–1 °C under CA	Reduced CI, ripening, and oxidative stress	Singh and Singh (2012)
1-MCP	'Autumn Giant', 'Black Beauty'	500 ppb	60 days at 0 °C under MAP	Reduced softening and maintained quality	Erkan and Eski (2012)

(continued)

Table 2 (continued)

Chemicals	Cultivars	Concentrations	Storage conditions	Inferences	References
1-MCP	'Black Amber', 'Red Lane', 'Fortune', 'Yummy Beaut', 'Black Splendor'	0.5 μL L^{-1}	30 days at 0 or 10 °C + shelf at 20 °C with 90% RH	Reduced ethylene production and showed maintained biochemical quality	Minas et al. (2013)
1-MCP	'Songold'	0.6 μL L^{-1}	50 or 30 days at 0 and 8 °C + 5 days on shelf at 20 °C	Showed higher fruit firmness and maintained biochemical quality	Velardo-Micharet et al. (2017)

senescence of the treated fruit species (Serrano et al. 2003). Cadaverine (CAD), putrescine (PUT), spermine (SPM), and spermidine (SPD) concentrations were found to be directly correlated with the hot water dips, CI tolerance, and higher firmness in plums (Abu-Kpawoh et al. 2002). Prestorage application of PUT (1 or 2 mM) suppressed ethylene production, reduced the respiration rate, reduced ACS, ACO, ACC, Exo-PG, Endo-PG, PE, and EGase activities with higher firmness and quality (Khan et al. 2007). The treatment of PUT (1 mM PUT) 1 week before commercial harvest in 'Angelino' plums led to delayed ethylene production, lower ripening, with higher firmness, SSC, TA, carotenoids, antioxidants, and ascorbic acid concentration during cold storage at 0 ± 1 °C for 42 days (Table 2; Khan and Singh 2008a). Similarly, a spray of 2 mM PUT 1 week before harvest in 'Angelino' plums resulted in lower ethylene production, respiration rate, inhibition in fruit ripening with higher firmness, SSC, TA, carotenoids, ascorbic acid contents, and antioxidants during cold storage at 0 ± 1 °C for 42 days (Table 2; Khan and Singh 2008b). Likewise, preharvest spray of 2 mM PUT in 'Angelino', 'Black Amber', and 'Amber Jewel' plums resulted in delayed ethylene production, lower rate of respiration, impeded ripening, reduced ACS, ACO, and ACC enzymes activities, along with higher firmness, levels of SSC, TA, carotenoids, antioxidants, and ascorbic acid in fruit kept for 13 days at 20 ± 1 °C (Khan and Singh 2010).

Aminoethoxyvinylglycine

Aminoethoxyvinylglycine (AVG) is known to retard ethylene biosynthesis by inhibiting the ACS activity in a competitive way. As ACS is a major enzyme that plays an imperative role in the biosynthetic pathway of the ethylene biosynthesis, reduction of its activity can effectively extend the storage life of the plum fruit (Singh and Khan 2010). The reduced activity of ACS enzyme suppressed S-adenosyl methionine conversion into ACC and, subsequently, retarded fruit ripening, and the response is dependent upon the cultivar and maturity at harvest (Khan and Singh 2010). Ozturk et al. (2015) reported increased phenolic contents during cold storage at 0 °C for 4 weeks in AVG-treated 'Black Beauty, 'Black Amber', and 'Friar' plum fruit, respectively.

Nitric Oxide

Nitric oxide (NO) is a multifunctional signaling molecule modifying various physiological processes in plants. It reduces the production of ethylene by binding with ACC and ACO enzymes to form a stable ACC–ACC oxidase–NO complex (Manjunatha et al. 2010). Postharvest NO fumigation of 'Amber Jewel' plum led to reduced CI, alleviated flesh browning, and enhanced shelf life of up to 7 weeks of cold storage at 0 °C (Table 2; Singh et al. 2009b). Sharma and Sharma (2014)

reported that the application of NO to 'Santa Rosa' plum reduced malondialdehyde (MDA) contents, phenyl aminialyase (PAL) and pectin methyl esterase (PMC) enzymes activities, CI, and internal browning throughout cold storage for 30 days at 2 °C. The combined application of NO and SA maintained fruit firmness and reduced ethylene production and electrolyte leakage, leading to the increased shelf life of 'Santa Rosa' plum for up to 6 days at 21 °C (Table 2; Sharma and Sharma 2016).

Salicylic Acid

Salicylic acid (SA) is an anti-ethylene compound that can retard the ripening of fruit. Increased maturity index, SSC, pH, and weight loss, and decreased fruit firmness, acidity, ascorbic acid, phenolic contents, and the antioxidant level were observed in plums treated with the combined application of SA and PUT (Davarynejad et al. 2015). The combined treatment of NO and SA on 'Santa Rosa' plums showed higher fruit firmness, exhibited reduced production of ethylene having diminished membrane leakage, and ultimately led to the extension of shelf life for 6 days (Table 2; Sharma and Sharma 2016). Similarly, Luo et al. (2011) noted reduced CI, membrane leakage, and MDA contents with a delayed increase in PPO and POD enzymes activities in response to SA application in 'Qingnai' plum (Table 2).

Others

The application of 40 mg L^{-1} chlorine dioxide combined with 100 W ultrasound reduced ethylene production and respiration rate, and showed higher total flavonoids, reducing sugars, ascorbic acid, TA, and sensory quality for 60 days (Chen and Zhu 2011). Similarly, the application of 5 mM oxalic acid revealed reduced ethylene production, PME, PG activities, delayed softening, and inhibited flesh reddening for 20 days (Table 2; Wu et al. 2011). Similarly, the combined treatment of 40 mM ascorbic acid and 1% chitosan resulted in decreased respiration rate, color changes, fruit softening, and activities of PME, PAL, and PG enzymes for 20 days (Table 2; Liu et al. 2014).

Molecular Aspects of Ripening

The molecular mechanism associated with plum fruit ripening has also been studied to enhance the understanding of various factors regulating fruit ripening behavior among several plum cultivars (El-Sharkawy et al. 2007, 2008, 2009). Due to the

climacteric nature, plum ripening is controlled by precise endogenous ethylene production and its prestorage exogenous applications. The ethylene perception and signal transduction components (EPSTC) have been characterized in plums. The EPSTC comprise a total of four in number, including two *Ps-ERS1* and *Ps-ETR1*, ethylene-responsive element binding factor (ERF), and CTR1-like proteins. The plum fruit with early maturity showed climacteric ripening patterns, which concurred with a sharp increase in the four EPSTC levels in the ethylene-dependent mode, whilst late-maturing plum fruit exhibited a comparatively suppressed pattern of climacteric peaks during ripening with only concomitant *Ps-ETR1* (not *Ps-CTR1*) accumulation of mRNA in an ethylene-independent way (El-Sharkawy et al. 2007). Variations in the production of ethylene perceived among the cultivars of plum fruit (Abdi et al. 1997b) might be owing moderately to differences in the accumulation rates of several ethylene biosynthesis, perception, and subsequent signal transduction cascades. This behavior might also be associated with the genotypic or 'allelotypic' variations (El-Sharkawy et al. 2007, 2008, 2009). Nevertheless, only allele factors cannot elucidate all significant phenotypic differences during fruit ripening. Furthermore, significantly higher accumulation of different ripening-linked genes in the treated fruit with some antagonist of the ethylene, i.e., 1-MCP, proposes that the signaling of the ethylene is not necessarily important for the signals that regulate fruit ripening. Hence, it is hypothesized that some other possible signaling pathway is as important as ethylene (El-Sharkawy et al. 2008). The auxin-binding protein 1 (ADBP1) plays a critical role in the ripening of plum fruit. The *PslABP1* expresses differently in the ripening of the early- and late-harvested plums (El-Sharkawy et al. 2012). Anthocyanins are important coloring pigments in plum. With the progression of plum fruit development towards ripening, *PsPAL*, *PsCHS*, *PsCHI*, *PsF3H*, *PsDFR*, *PsLDOX*, and *PsUFGT* play critical roles in the biosynthesis of anthocyanins (Cheng et al. 2016). The transcription factors such as MYB and bHLH also play a significant role in the enhancement of anthocyanins of plums during their ripening physiology (Fang et al. 2016).

Postharvest Handling and Storage

Precooling

After harvest, precooling is recommended to remove the heat absorbed in the fruit. It is essential to lower the temperature of fruit, which, in turn, reduces the metabolic activities during the subsequent storage conditions. It has been reported that a delay in the precooling of the harvested fruit may significantly reduce the quality of plums (Guerra and Casquero 2009). The forced-air cooling of plums cv. 'Santa Rosa' after harvest and before transportation to the packing house significantly reduced mechanical damage and the rate of respiration. Moreover, it also conserved the quality of fruit and extended the potential shelf life. It is suggested that the precooling of plum fruit should start within the few hour after harvest and the fruit should

reach an optimal temperature of storage within 18–24 h after harvesting (Mitchell 1986). A controlled delayed precooling (up to 48 h after harvest) resulted in a short shelf life of 10 days of 'Green Gage' plums as compared to the recommended precooling treatment (Guerra and Casquero 2009).

Heat Treatments

The use of chemicals has now been discouraged due to several environmental and food safety regulations. Alternatively, heat treatments have been used extensively to control postharvest diseases and to regulate the ripening physiology of fruit crops. Moreover, interest has been increased to control diseases, insect pests, induce resistance against CI incidence, delay ripening, and to prolong the storage or shelf life of various fruits. Similar to other fruits, heat treatments have also been used in the postharvest technology of plums. Dipping of plums in hot, 45 °C water for 10 min reduced firmness loss, ethylene production, and respiration rate, along with higher retention of polyamines for 14 days under cold storage (Valero et al. 2002). The 'Black Star' plums immersed in hot water at 45 °C for 10 min reduced weight loss, ethylene production, and the respiration rate (Serrano et al. 2004). Heat shock treatment of plums in hot water at 55 °C for 2 min following cold acclimation reduced MDA production and alleviated the CI development in 'Sanhua' plum fruit (Sun et al. 2010). The treatment of green 'Qingnai' plums with hot air (45 °C) for 5 h reduced ethylene biosynthesis, respiration rate, fruit softening, and green color loss. Moreover, it also reduced the activities of PG and PME, with higher SSC and TA for 20 days at 20 °C (Luo et al. 2010).

Cold Storage

Cold storage has been recommended for the extension of storage life and fruit quality maintenance during prolonged marketing and distant transport (Singh 2010). Similarly, low-temperature storage is an imperative factor for determining the shipping or storage potential of plum fruit. The market or storage life has been largely restricted by CI symptoms development. However, the CI development rate in plums generally depends on the type of cultivars, storage temperatures, harvest maturity, and orchard-related factors (Ward and Melvin-Carter 2001). The CI symptoms have been observed to occur during the storage of various stone fruits, including plums, below 10 °C. However, the 2.2–7.6 °C temperature range is known as the 'killing temperature zone or danger zone', during which the CI development rate in stone fruits is known to occur rapidly in contrast to a temperature range below or above the stated limit (Singh 2010). Hence, the storage of fruit above 0.5–2 °C (freezing point) is generally recommended for plums. Plum cv. 'Friar' stored at 0 and 2 °C suppressed ethylene production and the development of translucency, abnormal softening, and flesh reddening, as compared to fruit kept at 5 or 15 °C (Wang et al. 2016).

Controlled Atmosphere Storage

Under the CA environment, the concentration of CO_2 is raised and O_2 is lowered to reduce ethylene production and the respiration rate to delay ongoing fruit ripening, alleviate physiological disorders, and impede postharvest decay (Kader 2003; Ali et al. 2016b). The optimal storage temperature supplementation and the relative humidity (RH) with CA have been reported to be highly useful to conserve fruit quality for longer time periods. However, the response of various fruits or cultivars under CA is normally influenced by various factors, including cultivar, storage temperature, maturity stage, exposure duration, and interaction with prestorage chemical treatments (Saltveit 2003). The stone fruit storage potential can be extended under the CA conditions, as it has been reported to reduce or delay CI symptoms development in plums. The observed beneficial influences of CA storage on Japanese and European plums are delayed ripening of fruit, reduced ethylene biosynthesis, and respiration rate, and inhibited softening, color change, and reduced CI incidence (Table 3; Brackmann et al. 2001; Elzayat and Moline 1995). In the Japanese plum fruit, the use of CA comprising 2.5–10% CO_2 and 1–5% O_2 at 0 °C exhibited favorable effects. However, the cultivar-dependent requirement of CA storage has not been reported for certain and needs further investigation. The fruit treated with 500 nL L^{-1} 1-MCP, prior to CA storage containing 1.8% O_2 and 2.5% CO_2, has been reported to reduce brown rot, internal breakdown, weight loss and firmness loss at 0–3 °C for 80 days (Table 3; Menniti et al. 2006). Similarly, 'Black Amber' Japanese plums treated with 0.6 μL L^{-1} 1-MCP stored in CA comprising 2.5% O_2 and 3% CO_2 showed reduced fruit ripening, retarded lipid peroxidation, and decreased severity and incidence of CI symptoms for 56 days at 0–1 °C. Similarly, the same treatment also alleviated the oxidative stress, as compared to the control (Table 3; Singh and Singh 2012). Similarly, 'Black Amber' Japanese plums stored in CA containing 2.5% O_2 and 3% CO_2 showed reduced lipid peroxidation, CI development, inhibited ROS production, and higher TA and flesh firmness for 56 days at 0–1 °C (Table 3; Singh and Singh 2013).

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is normally created by packing the fresh produce in the polymeric films of various O_2, CO_2, and H_2O permeabilities. However, the response of the sorted commodities under MAP films largely depends upon the storage temperature, maturity stage, and interaction with possible prestorage chemical applications (Saltveit 2003). MAP has been found to extend the postharvest shelf or storage life and conserve the fruit quality attributes of the Japanese or European plums. The packaging of plum fruit under polymeric MAP films) with a suitable permeability and thickness can significantly reduce the weight loss of the fruit during transport and storage (Kluge et al. 1999; Khan and Singh 2008b).

Table 3 Response of plum fruit to controlled and modified atmosphere storage

Cultivar	Storage conditions	Inferences	References
'Angeleno'	6 days at −0.5 °C + 12 days at 7.5 °C or 18 days at 7.5 °C under 5% O_2 + 10% CO_2	Retarded ethylene production with higher firmness for 4–5 weeks	Maré et al. (2005)
'Angeleno'	80 days at 0 °C + 14 days at 20 °C under 1.8%O_2 + 2.5%CO_2 + 300 or 500 nL L^{-1} 1-MCP	Reduced fruit rot and internal breakdown	Menniti et al. (2006)
'Autumn Giant'	60 days at 0 °C + 500 ppb 1-MCP under MAP	Reduced softening, respiration rate, ethylene production, weight loss, and flesh browning with higher firmness, TA, and TSS	Erkan and Eski (2012)
'Angeleno'	35 days at 1 ± 1 °C with 90% RH under MAP	Delayed ripening and maintained quality	Briano et al. (2015)
'Ariddo di Core'	21 days at 1 ± 1 °C with 90–95% RH under MAP	Higher firmness, SSC, TA, delayed color changes, and chlorophyll degradation	Giuggioli et al. (2016)
'Angeleno'	60 days at 1 ± 1 °C with 90–95% RH under MAP	Higher firmness with maintained quality attributes	Peano et al. (2017)
'Black Amber'	35 days at 2 °C with 90% RH under MAP	Higher phenolics, cyanidin-3-rutinoside, cyanidin-3-glucoside, and carotenoids	Díaz-Mula et al. (2011a)
'Black Beauty'	60 days at 0 °C + 500 ppb 1-MCP under MAP	Reduced softening, respiration rate, ethylene production, weight loss, and flesh browning with higher firmness, TA, and TSS	Erkan and Eski (2012)
'Black Amber'	56 days at 0–1 °C under 1% O_2 + 3% CO_2, 2.5% O_2 + 3% CO_2	Reduced CI, ripening, and reduced oxidative stress	Singh and Singh (2012)
'Black Amber'	56 days at 0–1 °C under 1% O_2 + 3% CO_2, 2.5% O_2 + 3% CO_2	Reduced CI, ROS production, and maintained antioxidative and biochemical quality	Singh and Singh (2013)
'Black Amber'	56 days at0–1 °C under MAP	Reduced CI, ROS production, and maintained antioxidative and biochemical quality	Singh and Singh (2013)
'Golden Globe'	35 days at 2 °C with 90% RH under MAP	Higher phenolics, cyanidin-3-rutinoside, cyanidin-3-glucoside, and carotenoids	Díaz-Mula et al. (2011a)
'Golden Globe'	35 days at 2 °C with 90% RH under MAP	Decelerated changes in color, softening, TA with increased TSS	Díaz-Mula et al. (2011b)
'Laetitia'	6 days at −0.5 °C + 12 days at 7.5 °C or 18 days at 7.5 °C under 5% O_2 + 10% CO_2	Retarded ethylene production with higher firmness for 4–5 weeks	Maré et al. (2005)
'Laetitia'	60 days at 0.5 °C under 2 kPa O_2 + 2 kPa CO_2 + 0.6 μL L^{-1} 1-MCP	Delayed ripening and internal breakdown	Steffens et al. (2014b)

(continued)

Table 3 (continued)

Cultivar	Storage conditions	Inferences	References
'Laetitia'	60 days at 0.5 °C under 2 kPa O_2 + 5 kPa CO_2, 1 kPa O_2 + 3 kPa CO_2	Reduced internal breakdown and maintained quality	Steffens et al. (2014b)
'Larry Ann'	35 days at 2 °C with 90% RH under MAP	Higher phenolics, cyanidin-3-rutinoside, cyanidin-3-glucoside, and carotenoids	Díaz-Mula et al. (2011a)
'Larry Ann'	35 days at 2 °C with 90% RH under MAP	Decelerated changes in color, softening, TA, with increased TSS	Díaz-Mula et al. (2011b)
'Laetitia'	21 days at 0.5 °C with 96 ± 2% RH + CO_2 absorber with low ethylene under MAP	Delayed fruit ripening due to reduced ethylene and respiration rates	Stanger et al. (2017)
'Ramasin'	21 days at 1 ± 1 °C with 90–95% RH under MAP	Higher firmness, SSC, TA, delayed color changes, and chlorophyll degradation	Giuggioli et al. (2016)
'Santa Rosa'	3% O_2 + 2% CO_2, 3% O_2 + 4% CO_2	Delayed color changes, higher firmness, and reduced internal breakdown	Eksteen and Truter (1987)
'Sapphire', 'Songold'	6 days at −0.5 °C + 12 days at 7.5 °C or 18 days at 7.5 °C under 5% O_2 + 10% CO_2	Retarded ethylene production with higher firmness for 4–5 weeks	Maré et al. (2005)
'Songold'	35 days at 2 °C with 90% RH under MAP	Higher phenolics, cyanidin-3-rutinoside, cyanidin-3-glucoside, and carotenoids	Díaz-Mula et al. (2011a)
'Songold'	35 days at 2 °C with 90% RH under MAP	Decelerated changes in color, softening, TA, with increased TSS	Díaz-Mula et al. (2011b)
'Tegan Blue'	42 days at 0 ± 1 °C with 90 ± 5% RH + 1 μL L^{-1} MCP under MAP	Reduced ethylene production, respiration rate, softening, ACS, ACO, and ACC, Exo-PG, Endo-PG, PE, and EGase activities, showed higher firmness, SSC, TA, carotenoids, antioxidants, and ascorbic acid	Khan and Singh (2008a, b, c)

'Laetitia' plum fruit packed in microperforated polypropylene or polyethylene bags showed lower weight loss, higher firmness, and reduced ripening compared to control fruit during 49 days of cold storage (Crouch 1998). In another study, CI incidence and decay has been found to be considerably less in MAP-packed 'Amarelinha' plum fruit than non-packed control fruit (Table 3; Kluge et al. 1999).

The storage of 'Friar' plums under MAP box liners resulted in delayed skin color changes and reduced CI symptoms and weight loss during low-temperature storage at 0 °C for 45 days (Cantín et al. 2008). The combined application of LifeSpan® polyethylene MAP bags and 1-MCP resulted in extended storage life in 'Tegan Blue' plum fruit. It was observed that fruit ripening was delayed, with reduced color changes, ethylene production, respiration rate, and fruit softening, without any

adverse influences on the quality of 'Tegan Blue' plum fruit (Khan and Singh 2008b). The combined use of MAP and 1-MCP was found to be more suitable to inhibit the softening of fruit and to impede skin color changes as compared to either of the treatments alone. Nevertheless, it was found that the respiration rates of MAP-packed fruit were significantly higher during 10 days of shelf life after 35 and 42 days of low-temperature storage, compared to the non-packed control fruit (Table 3). In contrast, the ethylene production rate was markedly suppressed in MAP-packed plum fruit (Khan and Singh 2008b).

The storage of yellow and purple plums under MAP showed reduced color changes, fruit softening, higher TA, SSC, and sensory quality during cold storage at 2 °C for 35 days (Díaz-Mula et al. 2011b). Similarly, the storage of purple and yellow plums under MAP resulted in increased phenolics in the peel and flesh, as well as cyanidin-3-rutinoside and cyanidin-3-glucoside during cold storage at 2 °C for 35 days (Díaz-Mula et al. 2011b). The combined treatment of 1-MCP (0.5 μl L^{-1}) and MAP in 'Black Beauty' and 'Autumn Giant' plums exhibited reduced respiration rate, ethylene production, fruit softening, weight loss, and flesh browning. Moreover, it also resulted in higher firmness, TA, and SSC for 60 days cold storage (Erkan and Eski 2012). Japanese plums 'Black Amber' fruit treated with 0.6 μL L^{-1} and kept under MAP (~10% O_2 and 3.8% CO_2) retarded lipid peroxidation, showed reduced ripening, diminished incidence of CI, and suppressed ROS generation for 56 days at 0–1 °C (Singh and Singh 2012). Similarly, Japanese plums cv. 'Black Amber' stored under MAP with ~10% O_2 and 3.8% CO_2 showed reduced CI development, lipid peroxidation, ROS production, and higher flesh firmness for 56 days at 0–1 °C (Singh and Singh 2013). The 'Angeleno' plums stored under active MAP with 10.0 kPa of O_2 + 5 kPa of CO_2 showed a reduced mass loss and maintained biochemical and nutraceutical attributes for 60 days cold storage at 1 °C (Peano et al. 2017). Similarly, 'Ariddo di Core' and 'Ramasin' European plums showed delayed color changes, higher firmness, SSC, TA, and chlorophyll contents for 21 days cold storage at 1 °C under MAP conditions (Giuggioli et al. 2016). Likewise, the storage of 'Laetitia' plums in low-density polyethylene MAP bags with CO_2 absorber resulted in an enhanced cold storage life for 60 days at 0.5 °C (Table 3; Stanger et al. 2017).

Intermittent Warming

Intermittent warming (IW) is a management approach that involves the transfer of fruits to 20 °C conditions for 1 day after every 10–14 days cold storage period. IW has been found to minimize CI incidence in various stone fruits, including plum (Kotze et al. 1989). The shifting of the produce leads to enhanced metabolic activities in response to IW of the chilled tissue that eventually helps to repair membrane damage and certain metabolic pathways. The increased unsaturation of the fatty acids of the damaged membrane lipids during IW results in the maintained membrane functions to escape the CI-induced damages (Wang 1993). In 'Victoria' plum

fruit, an increase of the temperature to 18 °C for a period of 2 days between days 15 and 20 of cold storage at −1 °C resulted in delayed appearance of CI symptoms. Likewise, 'Songold' plum fruit subjected to IW at 20 °C for 1 day following 14 days of cold storage at −0.5 °C led to extended storage life for 4 weeks, with substantially reduced internal browning incidence (Kotze et al. 1989). Similarly, combined application of IW and polyethylene MAP bags reduced the severity and incidence of CI, skin browning, and flesh discoloration in 'Ruby' plum cold stored (2–5 °C) for 48 days (Ding et al. 2010).

Edible Coatings

Chitosan

Edible coatings are very important to maintain the internal physiology of the fruits and reduce the postharvest losses (Zhang et al. 2011). The application of chitosan coating reduced the respiration rate, fruit weight loss, and ripening index in 'Giant' and 'Stanley' plums and increased the shelf life to 40 days when stored at 0 °C conditions (Table 4). Similarly, the combined application of chitosan and ascorbic acid decreased the activities of PAL, PG, and PME enzymes. Moreover, the activities of SOD, POD, and CAT enzymes were also higher in combined treatments than in controls (Table 4; Liu et al. 2014).

Alginate

Alginate is a naturally occurring polymer that is found in brown algae (Acevedo et al. 2012). It has been reported to maintain the postharvest quality of various fruits, including plum. Plum fruit cvs. 'Black Amber', 'Larry Ann', Golden Globe', and 'Songold' treated with alginate coating showed a reduced mass loss, with higher bioactive compounds such as carotenoids and anthocyanins in 20 days of cold storage at 5 °C (Valero et al. 2013).

Carboxymethyl Cellulose

The application of carboxymethyl cellulose coating in combination with gamma irradiation maintained higher chlorophyll contents, along with reduced yeast and mold growth, for 45 days under cold storage at 3 ± 1 °C in 'Santa Rosa' plum fruit (Table 4; Hussain et al. 2015).

Table 4 Effect of different edible coatings and irradiation on postharvest quality and physiology of plums

Chemicals	Cultivars	Concentrations	Storage conditions	Inferences	References
AsA + CTS	'Sanhuali'	40 mM AsA + 1.0% CTS	20 days at 5 ± 1 °C with 90 ± 5% RH	Combined treatment decreased respiration rate, color changes, fruit softening, and activities of PME, PAL, and PG enzymes. Activities of SOD, POD, and CAT enzymes were also higher in combined treatment	Liu et al. (2014)
Alginate	'Black Amber', 'Larry Ann', 'Golden Globe', 'Songold'	1 and 3% alginate	35 days at 2 °C with 90% RH + 3 days on shelf at 20 °C	Delayed postharvest ripening, reduced fruit weight and acidity loss. Maintained higher carotenoid and anthocyanin content in both treatments	Valero et al. (2013)
AV gel, AA gel, and RO	'President'	2% RO, 2% AV gel, and 2% AA gel	28 days at 2 °C with 90% RH + 2 days on shelf at 20 °C with 85% RH	AA and RO delayed fruit ripening and extended shelf life to 28 days at 2 °C	Martínez-Romero et al. (2017)
CTS	'Stanley', 'Giant	1% CTS	40 days at 0–1 °C with 90 ± 5% RH	Reduced weight loss, respiration rate, and fruit decay in 'Stanley' as compared to 'Giant'	Bal (2013)
CMC + gamma radiation	'Santa Rosa'	1.0% CMC, 1.5 kGy	21 days at 25 ± 2 °C + 45 days at 3 ± 1 °C	Higher chlorophyll content at both storage conditions, along with reduced yeast and mold content after 45 days under cold storage	Hussain et al. (2015)
HPMC, OEO, BEO	'Formosa'	HPMC (4%), OEO and BEO (0.5, 1.0, 1.5, 2.0)	30 days at 5 ± 1 °C + 14 days at 23 ± 2 °C	Reduced respiration rate and fruit weight loss, with maintained quality	Choi et al. (2016)
Irradiation	'Santa Rosa'	1.2–1.5 kGy	35 days at 25 ± 2 °C with 70% RH	Reduced respiration rate, weight loss, with higher water soluble pectins, firmness, chlorophyll, SSC, and acceptability	Hussain et al. (2013)
Irradiation + Chitosan	'Kelsey'	1 kGy + 3% chitosan	21 days at 0 ± 1 °C	Reduced weight loss, respiration rate, and maintained biochemical quality	Salem et al. (2016)
Carnauba wax	NM	4.5% and 9%	–	Inhibited *Monilinia fructicola*-induced decay	Gonçalves et al. (2010)

Irradiation

Irradiation has become a very effective way for processing and preserving various food products, including fresh fruits. Irradiation has also been recognized as a suitable alternative to chemical compounds as a mode of delaying fruit ripening and senescence (Hussain et al. 2013). The application of 1.2–1.5 kGy to 'Santa Rosa' plums markedly inhibited fruit decay during 16 days at ambient storage (Table 4). The same dose also effectively maintained the fruit quality of plums for 35 days in cold storage (Hussain et al. 2013). Similarly, combined treatment of 1% carboxymethyl cellulose coating and 1.5 kGy markedly delayed fruit firmness, showed higher water pectin contents, anthocyanins, and related biochemical quality of plum fruit cv. 'Santa Rosa' for 20 days at ambient temperature and 45 days under low-temperature conditions, respectively (Table 4; Hussain et al. 2015).

Postharvest Oxidative Stress

Harvested fruit are living entities and continue their respiration and transpiration at harvest and during storage. The advanced ripening stages terminate at senescence and eventually lead to fruit death and cause economic losses. The ripening has been known as oxidative in nature and involves the production of certain ROS in the fruit tissues. However, failure or decrease in the ability of the antioxidant system eventually leads to oxidative breakdown, concurring with the advancement of the senescence process of plum fruit (Larrigaudière et al. 2009; Singh and Khan 2010; Singh and Singh 2013; Shah et al. 2017). The objective of all of the postharvest approaches is to prolong shelf or storage life of the plum, which have simultaneously been reported as oxidative stress factors. Therefore, it is clear that oxidative stress development in the postharvest stage is an indicator of the major stresses experienced by the fresh commodities (Toivonen 2004).

During postharvest supply chains, certain biochemical and physiological changes in the plum fruit may lead to the development of different disorders. The CI, internal browning, overripeness, and flesh translucency of plums have been accredited to unwanted influences of the postharvest oxidative stress. It has been reported that the development of CI in temperate fruits is due to the oxidative damages to membranes, which leads to abnormalities in the normal metabolic activities and physiology of the cells due to exposure to low temperature. The ROS production sites and their possible role in the physiology of cells are very complex. However, the fruit have developed an antioxidant defense system in order to manage the intricate oxidative stress during low-temperature storage. The oxidative stress during the postharvest life of plums can be directly assessed by measuring the ROS accumulation, increased lipid peroxidation, and instigated disintegration of the cell membranes and accumulation of the pro-oxidative induced brown pigments (Singh and Singh 2013). The indirect measurement is the determination of certain enzymatic and

non-enzymatic antioxidants in the fruit skin or flesh tissues (Ali et al. 2016b). Therefore, the comprehensive measurements of different antioxidative protective system components are crucial to validate their plausible roles in the quality of fruits with respect to different physiological storage disorders of plums (Singh and Singh 2012). It has been established that plants possess two different strategies to cope with the postharvest oxidative stress; tolerance and avoidance. Fruit during the postharvest stage do not adopt the strategy of 'avoidance' to alleviate ROS promotion. However, the level of oxidative stress 'tolerance' during postharvest in different fruits including plums has been related to their intrinsic antioxidative potential (Singh and Singh 2012). The oxidative stress can be managed with certain postharvest treatments. It has been shown that 'Qingnai' plums treated with SA showed alleviated CI, lower electrolyte leakage, and lipid peroxidation. The higher levels of these indices are indicative of the oxidative damage. Hence, SA application alleviated oxidative stress in 'Qingnai' plums cold-stored for 60 days (Luo et al. 2011). Similarly, a combined treatment with ascorbic acid and chitosan substantially reduced superoxide radical production and lipid peroxidation in 'Sanhuali' plums during storage at 5 °C for 20 days. This response was directly correlated with the higher activities of antioxidant enzymes such as POD, CAT, and SOD (Liu et al. 2014). Similarly, NO-treated 'Santa Rosa' plums also revealed lower lipid peroxidation and CI incidence, which are also indicators of oxidative damage (Steffens et al. 2014a, b, c; Sharma and Sharma 2016).

Postharvest Diseases and Their Control

Plums are highly perishable climacteric fruit. They undergo prompted ripening that ultimately reduces their shelf life potential and fruit are liable to certain postharvest disease infestations. Increased disease infestations result in excessive postharvest economic losses (Northover and Cerkauskas 1998; Zhang et al. 2010; Hussain et al. 2013). Some appropriate postharvest disease control measures are required to reduce the pathogen-induced losses in plums. Postharvest plum diseases can be controlled by fungicides (Northover and Cerkauskas 1998), some natural antagonists (Zhang et al. 2010), edible coatings (Gonçalves et al. 2010), and irradiation (Hussain et al. 2013). Postharvest application of flusilazole, tebuconazole, and myclobutanil were found to be highly effective for controlling *Monilinia fructicola*-induced disease in European plums (Northover and Cerkauskas 1998), whilst a natural antagonist *Aureobasidium pullulans* PL-5 controlled the growth of *Monilinia laxa* on 'Angeleno' plums (Zhang et al. 2010). The postharvest application of *Copernicia cerifera* wax coating significantly reduced the *Rhizopus stolonifer*-induced rot in plums (Gonçalves et al. 2010). Besides fungicides, antagonists, and edible coatings, the use of irradiation has also been found to be highly suitable for reducing the postharvest disease incidence of plums (Hussain et al. 2013). Gamma irradiation at dose of 1.5–2 kGy substantially inhibited the decay of 'Santa Rosa' plums for 16 days at ambient conditions (Hussain et al. 2013). Similarly, combined

treatment with 3% chitosan and 1 kGy gamma irradiation markedly inhibited the postharvest disease incidence of 'Kelsey' plums (Salem et al. 2016). The application of *Kloeckera apiculata and Pichia membranaefaciens* markedly inhibited *Monilinia fructicola-induced* brown rot of 'Maili' plum fruit (Zhang et al. 2017).

Physiological Disorders

Chilling Injury

The low-temperature storage of plums may lead to CI symptoms development, which appears as flesh translucency, flesh browning, flesh bleeding, and mealiness (Manganaris et al. 2008b; Singh et al. 2009a). The symptoms of CI proliferate and become evident when plums are transferred to ambient temperature conditions for ripening. Generally, flesh discoloration appears during low-temperature storage or immediately after it. On the other hand, flesh symptoms are associated with advanced stages of CI development during fruit ripening after storage. The flesh browning encompasses mesocarp tissue darkening depending upon the severity and it is generally found when the fruit are harvested prior to the optimum maturity stage. The tissue deterioration or senescence normally leads to alterations in the permeability of membranes and interaction between polyphenol oxidase and phenols, which are mostly found in the separate compartments of cells and cause enzymatic browning (Ali et al. 2016a). The formation of a gelatinous translucent area in flesh tissues around the stone is known as gel breakdown, flesh translucency, or translucency. Its increased severity usually covers more area of flesh spreading outwards to the pit region and leads to browning of the tissues during the advanced stages. It is frequently common in the mature and overmature fruit to experience CI (Abdi et al. 1997b; Wang et al. 2016).

Gel Breakdown

Anomalous activities lead to a physiological disorder in plums known as gel breakdown (GB) (Taylor et al. 1993a). In this physiological disorder, plums generally have a normal appearance of their external surface but characterized with inner mesocarp gelatinous breakdown having healthy and good looking outer mesocarp appearance (Taylor 1996). In severe conditions, gel breakdown spreads in the outward position and changes into brown-colored discoloration, and has been found to be correlated with juiciness loss of plums. It was observed that, when the pectic substances and cell membrane integrity lost the ability to bind the cell fluids, it leads to gel breakdown (Taylor 1996). As the cell membrane permeability increases, the fluid of cells flows out into the area of cell walls, at which pectins binding occurs. Therefore, gel breakdown has been found to be associated with juiciness loss and is

limited to the inner area of the mesocarp, probably owing to the pattern of ripening within a particular plum cultivar, such as 'Songold' (Taylor et al. 1993b). When ultrastructural investigation was carried out on plum cv. 'Songold', it was found that gel breakdown disorder was correlated with cell wall empty spaces. Higher gel breakdown incidence was detected in overmature cold-stored plum fruit cv. 'Songold', probably due to early membrane integrity loss (Taylor et al. 1994b). The reduced incidence of overripeness in fruits of cv. 'Songold' plums after extended cold storage and ripening at shelf conditions was associated with increased internal browning and gel breakdown (Taylor et al. 1993a). Gel breakdown incidence was already present in the overmature fruit (Taylor et al. 1994a), showing that gel breakdown occurrence is not a true cold-stored correlated chilling physiological disorder (Taylor 1996). Therefore, the development of gel breakdown has been possibly associated with certain physiological alterations during fruit ripening or senescence. Gel breakdown was developed earlier in cv. 'Songold' plums kept at a dual temperature, in contrast to fruit storage at −0.5 °C alone. However, the incidence of gel breakdown was substantially higher in plums stored under a single temperature than the lot kept at a dual temperature during the ripening of fruit at 10 °C (Taylor et al. 1994a). It is worthy to mention that about 60% of plums exhibited gel breakdown when kept under both temperature regimes, showing that none of the approaches can be used to control the gel breakdown effectively (Taylor 1996).

Internal Browning

Internal browning in plums has been characterized as a CI disorder. In this physiological disorder, plum fruit show brown coloration in mesocarp tissues and has been correlated with loss of juiciness. It is important to mention that plums with internal browning generally have a normal surface appearance (Taylor 1996). Rapid fruit senescence and tissues deterioration have also been found to be associated with the internal browning of plums. The internal plum browning results in the collapse of the cell membrane with substantially increased membrane permeability (Taylor et al. 1993a). Flesh browning occurs due to the oxidation of phenolics compounds in the presence of polyphenol oxidase enzyme (Taylor et al. 1993a). Internal flesh browning may also occur due to the immature harvesting of fruits, possibly owing to higher polyphenols concentration (Taylor 1996).

Mealiness

Mealiness refers to the reduced juiciness of the plum fruit. It is primarily associated with decreased cell wall hydrolases activities, which eventually influence the metabolism of the pectins (Manganaris et al. 2008c). The alterations in the metabolism of the pectin contents leads to the mealiness due to the formation

of cell fluids from the calcium pectate with higher molecular weight pectin contents or by decreased activities of endo-1,4-β-mannanase, endo-1,4-β-glucanase, α-arabinosidase, β-galactosidase, and expansins, finally leading to the advanced alterations of the metabolism of cell walls and decrease of intercellular adhesions (Brummell et al. 2004; Obenland et al. 2003).

Overripeness

In plums, overripeness normally occurs owing to prompt ripening and senescence of fruit. However, it is considered a physiological disorder in which plums become excessively soft, with enormous free juice in the fruit tissues. Moreover, in some extreme cases, mesocarp tissues become excessively translucent under subepidermal areas, whereas the remaining inner tissues of mesocarp maintain normal appearance (Taylor 1996).

Translucency

The translucency of the plum flesh is the breakdown of the translucent gelatinous part of the mesocarp cells around the stones. These symptoms of translucency primarily develop during shelf storage following cold storage. Moreover, membrane permeability changes have also been found to be associated with its development (Taylor et al. 1993c). The development of water-soaked spaces in outer mesocarp tissues takes place as a result of the overripening commonly known as translucency (Crisosto et al. 2007). The higher internal breakdown incidence was noted in 'Radiant', 'Gulf Ruby', and 'Shiro' plums with increased duration of low-temperature storage (Abdi et al. 1997b). The storage temperatures around the freezing point help to reduce the symptoms of translucency in the plums. It has been reported that the incidence of translucency was significantly decreased in 'Amber Jewel' plum fruit treated with NO, even after 7 weeks of low-temperature storage, along with 5 days on the shelf during the subsequent ambient storage conditions (Singh et al. 2009b). Recently, it has also been reported that the intensity of flesh translucency was significantly higher in 'Friar' plums stored at 5 or 10 °C, as compared to 0 or 2 °C conditions (Wang et al. 2016).

Conclusion

Numerous factors significantly influence the postharvest physiology, storage life, and fruit quality in plums. Various pre- and postharvest strategies can effectively be used to maintain quality and extend the storage life of plums. However, different

handling techniques need to be improved further throughout the postharvest supply chains, starting from harvesting, precooling, packing house operations, postharvest treatments, and different types of storage conditions to minimize postharvest losses with extended storage life potential and acceptable quality to the consumers.

AVG aminoethoxyvinylglycine, *B* boron, *Ca* calcium, *RH* relative humidity, *SSC* soluble solids concentration, *TPC* total phenolic content, GA_3 gibberellic acid, *K* potassium, *ppm* parts per million, *TA* titratable acidity, *AA* ascorbic acid, *MJ* methyl jasmonate, *Mg* magnesium, *N* nitrogen, *NAA* naphthalene acetic acid, *POD* peroxidase, *CAT* catalase, *APX* ascorbate peroxidase, *PUT* putrescine, *Ti* titanium, *ACS* 1-aminocyclopropane-1-carboxylic acid synthase, *ACO* 1-aminocyclopropane-1-carboxylic acid oxidase, *ACC* 1-aminocyclopropane-1-carboxylic acid

Ca calcium, ClO_2 chlorine dioxide, *MJ* methyl jasmonate, *NO* nitric oxide, *OA* oxalic acid, *PUT* putrescine, *RH* relative humidity, *TA* titratable acidity, *APX* ascorbate peroxidase, *POD* peroxidase, *CAT* catalase, *CI* chilling injury, *MDA* malondialdehyde, *PAL* phenyl ammonia lyase, *PME* pectin methylesterase, *PG* polygalacturonase, *ACS* 1-aminocyclopropane-1-carboxylic acid synthase, *ACO* 1-aminocyclopropane-1-carboxylic acid oxidase, *ACC* 1-aminocyclopropane-1-carboxylic acid, *Exo-PG* exo-polygalacturonase, *Endo-PG* endo-polygalacturonase, *PE* pectin esterase, *EGase* endo-1,4-β-d-glucanase, *SSC* soluble solid contents, *SA* salicylic acid, *CA* controlled atmosphere, *PPO* polyphenol oxidase, *1-MCP* 1-methylcyclopropene, *MAP* modified atmosphere packaging, *MACC* malonyl 1-aminocyclopropane-1-carboxylic acid

1-MCP 1-methylcyclopropene, *MAP* modified atmosphere packaging, *RH* relative humidity, *CI* chilling injury, *TA* titratable acidity, *SSC* soluble solids concentration, *ppb* parts per billion, *ROS* reactive oxygen species, *PE* pectin esterase, *PG* polygalacturonase, *ACS* 1-aminocyclopropane-1-carboxylic acid synthase, *ACO* 1-aminocyclopropane-1-carboxylic acid oxidase, *ACC* 1-aminocyclopropane-1-carboxylic acid, *Exo-PG* exo-polygalacturonase, *Endo-PG* endo-polygalacturonase, *EGase* endo-1,4-β-D-glucanase

AA Aloe arborescens, *APX* ascorbate peroxidase, *AsA* ascorbic acid, *AV Aloe vera*, *AVG* aminoethoxyvinylglycine, *BEO* bergamot essential oil, *CA* controlled atmosphere, *CAT* catalase, *CMC* carboxymethyl cellulose, CO_2 carbon dioxide, *CTS* chitosan, *HPMC* hydroxypropyl methylcellulose, *kGy* kilogray, *MACC* malonyl 1-aminocyclopropane-1-carboxylic acid, *OEO* oregano essential oil, *PAL* phenylalanine ammonia lyase, *PG* polygalacturonase, *PME* pectin methylesterase, *POD* peroxidase, *PPO* polyphenol oxidase, *RH* relative humidity, *RO* rosehip oil, *SOD* superoxide dismutase, *SSC* soluble solids concentration

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Postharvest Biology and Technology of Cherry

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Introduction

Cherry fruit, botanically, is a fleshy drupe containing a stony hard seed in the centre surrounded by a fleshy part. It belongs to the family Rosaceae and three main species of cherry are cultivated throughout the world: sweet cherry (*Prunus avium*), sour (pie or tart) cherry (*Prunus cerasus*) and ground cherry (*Prunus fruticosa*) but the commercially important species are sweet cherry and sour cherry (Fig. 1). Cherries are cultivated in temperate regions where winters are moderately cold. The cherry production is limited by cold mid-winter temperatures in colder regions. Thus, better cherry sites are often found near large water bodies that buffer the temperatures and on higher locations with sufficient cold air drainage (Iezzoni 2008). The world's annual sweet and sour cherry production were 2317956 and 1378216 tonnes, respectively. Turkey and Russian Federation were the leading producers in sweet and sour cherries respectively (FAOSTAT 2017). Commercial cultivation of sweet cherry is generally more difficult and expensive than sour cherry because great care is required throughout the supply chain to maintain high quality of sweet cherry destined to the fresh market (Looney and Jackson 2011).

Sweet cherry originated from the region between the Caspian and Black Seas. According to the earliest records, cherry was first domesticated in Greece; it was documented in detail around 300 BC (Hedrick 1914). Sweet cherries are mainly

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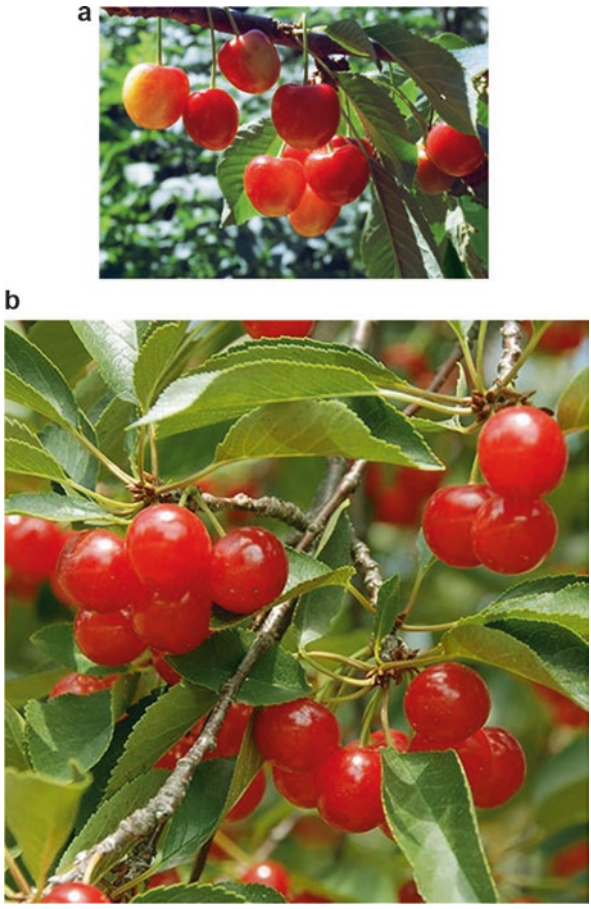

Fig. 1 Types of cherry. (**a**) Sweet cherry, (**b**) sour cherry, cv. 'Montmorency'

consumed as fresh and only a small percentage is processed into different products (McLellan and Padilla-Zakour 2004).

Sour cherry originated around the Caspian and Black Seas on the border of Europe and Asia (Webster 1996). Sour cherry cultivars are classified in three major groups: Amarelles, Morellos, and Marasca. Amarelles are clear fleshed cultivars and used for the production of cherry pies. Morellos are red-fleshed cultivars used for processed products such as juice and jam. Marasca cultivars are small and very dark-colored fruits used for making cherry wine and liqueurs (Iezzoni 1996; McLellan and Padilla-Zakour 2004).

The quality attributes of cherries are fruit size, skin colour, flavor, sweetness, sourness, firmness and stem colour and consumers' acceptability and market prices are dependent on these paamters (Dever et al. 1996). Several studies have reported high correlations between physicochemical properties (weight, appearances of skin and stem, TSS or SSC (total soluble solids or soluble solids content), TA (titratable acidity),

TSS/ TA ratio, firmness) and sensory parameters of sweet cherries (Crisosto et al. 2003; Dever et al. 1996; Kappel et al. 1996).

Cherries exhibit a very low calorific value. Sweet cherries have 63.0 kcal (263.34 kJ) per 100 g while sour cherries posses 50.0 kcal (209 kJ) per 100 g fresh weight (USDA ARS 2016). They also contain large number of nutrients and phytochemicals (McCune et al. 2011), which is one of the main reasons for their increasing demand and popularity in the human diet. Also, many epidemiological studies have reported various health benefits and disease preventing properties associated with the regular consumption of cherries (Ferretti et al. 2010; McCune et al. 2011).

Cherries are highly perishable and very difficult to handle after harvest. They are susceptible to bruising, desiccation and browning of stem (Petracek et al. 2002; Bernalte et al. 2003; Alique et al. 2005). They are also susceptible to various physiological and microbial disorders. Several postharvest technologies have been developed to increase the shelf life and market value of cherries. These include several processing and preservation methods meant for fresh market produce as well as processed cherry products.

Production

The top ten sweet and sour cherry-producing countries are given in Table 1. Production has rapidly increased due to high consumer demands throughout the world (Habib et al. 2017). Sweet cherries are cultivated in more than 40 countries worldwide and Turkey is the leading sweet cherry-producing country, with a production of 599,650 tons during 2016 (FAOSTAT 2017). Some varieties of sweet cherries are: 0900 Ziraat, Stark Gold, Regina, Bing, Burlat, Brooks, Coral Champagne, Chelan, Early Garnet, Garnet, Rainier, Royal Rainier, Tulare, MaxMa 14, Krymsk 5, Krymsk, Sweetheart, Sorati Lavasan, Zarde Daneshkade, Shishei, Siah Mashhad, Bing, Lambert, Early Lory, Giorgia, Van, MaxMa 60, GiSelA 6,

Table 1 Top ten cherry-producing countries for the year 2016 (FAOSTAT 2017)

Sweet cherry		Sour cherry	
Country	Production (tons)	Country	Production (tons)
Turkey	599,650	Russian Federation	230,443
United States of America	288,480	Poland	194,817
Iran (Islamic Republic of)	220,393	Turkey	192,500
Chile	123,224	Ukraine	156,450
Uzbekistan	95,267	United States of America	140,210
Italy	94,888	Iran (Islamic Republic of)	94,606
Spain	94,138	Serbia	80,596
Romania	73,834	Hungary	67,794
Greece	71,858	Uzbekistan	54,742
Syrian Arab Republic	69,153	Belarus	36,740

CAB 6P, Chelan, Prime Giant, Nimba, Pacific Red, Frisco, Crystal, Champaign, Lapins, Santina, and Royal Dawn.

The majority of the world's sour cherry producing countries belong to Eastern Europe and the Russian Federation is the leading sour cherry-producing country, with a production of 230,443 tons during 2016 (FAOSTAT 2017). Sour cherries are produced almost solely for processing. Besides canned, bottled, or dried end products, preserved and frozen sour cherries are also prepared for secondary food industrial uses, such as the baking, dairy, and confectionary industries. Some varieties of sour cherries are: Montmorency, Zhukovsky, Youth, Lyubsky, Turgenev, Rusinka, Enikeev's Memory, Łutówka, Kelleris 16, Újfehértói Fürtös, Debreceni Bőtermő, Schattenmorelle, Melitopolska Desertna, Vstrecha, North Star, Shalunia, Érdi Bőtermő, Cigány Meggy, Érdi Jubileum, Oblačinska, Crişana, Mocăneşti, Schattenmorelle, Nana, Tarina, and Ilva.

Fruit Development

The fruit development in cherry begins after the fertilization process and the ovary develops into the fruit. Soon after fertilization, fruit growth takes place rapidly. Some pistils wilt, while others develop into fruit (Hedhly et al. 2007). Cherry fruit growth follows a double sigmoid curve, similar to other *Prunus* spp. (Coombe 1976). It is divided into three stages. Stage I is characterized by the rapid growth of fruit. Stage II is characterized by a lag phase, in which hardening of endocarp and the development of embryo occurs. Stage III is characterized by second exponential growth of fruit, resulting in fruit maturation. The final fruit size is the result of cell number and cell size (Yamaguchi et al. 2004). Cell division occurs primarily during prebloom through stage I, resulting in an increase in cell number, and cell enlargement mainly occurs in stage III of fruit growth, resulting in an increase in fruit size (Olmstead et al. 2007).

Fruit size is an important trait in cherry, as it has a clear economic impact on crop value (Whiting et al. 2005). Several authors have studied the factors affecting fruit size. Olmstead et al. (2007) evaluated three cherry cultivars differing in fruit size and reported that it is the cell number and not cell size that is mainly responsible for differences in their fruit size. Also, the cell number is genetically controlled and the cultural practices that affect fruit size mainly do so through differences in the cell size, as the environment had no significant effect on cell number. The factors which affect the fruit size and quality are rootstock, crop load, and environmental factors (Whiting and Ophardt 2005; Lenahan et al. 2006). Some authors have also used external treatments to improve fruit quality (Zhang and Whiting 2011). The use of gibberellins has been shown to increase fruit size through cell enlargement (Lenahan et al. 2006) and has become standard practice in many sweet cherry production industries (Herrero et al. 2017).

Maturity Index and Harvest Index

Cherry maturation can be visualized with a change in exocarp color from green to red. During maturation, chlorophyll degrades and anthocyanins accumulate, resulting in the yellow background color and mahogany as blush. The maturity index is the ratio of sweetness due to sugars sourness due to the acids present in cherries. Thus, the maturity index is represented as the TSS/TA ratio. It is one of the widely accepted and major analytical measures of cherry quality (Crisosto et al. 2003). The increase in TSS/TA ratio increases the consumer perception of sweetness in cherries (Guyer et al. 1993). Sweet cherries are characterized by greater sweetness due to higher TSS/TA ratios, while sour cherries have lower TSS/TA ratios due to higher acid content and, thus, are less sweet. The TSS/TA ratios for sweet cherries and sour cherries range between 19.0 to 40.0 and 5.8 to 15.8, respectively (Serradilla et al. 2017).

The harvesting time has a significant impact on both cherry quality and the deterioration rate of cherry during storage. Cherries are non-climacteric and, thus, harvested ripe. This limits its marketing and storage. During fruit maturation, the increase in TSS and fruit metabolism affects the fruit skin color. Therefore, fruit harvested at a dark skin color reduces the storage time but improves fruit flavor and consumer acceptability. In contrast, lighter skin color lowers the consumer acceptability but improves the storage time. The proper adjustment of the harvesting time of a cultivar with its storage requirements is critical for maintaining high-quality fruit after long-term storage or transport (Zoffoli et al. 2017).

According to Aslantas et al. (2016), maturity stage during harvesting is very important for maintaining fruit quality and minimizing the fruit detachment force. Based on color and dimensions, sour cherries were divided into 5 different maturity stages (Fig. 2). The chroma value of outer fruit color was higher (50 %) than that of inner

Fig. 2 Appearance of the fruits in different maturity stages: it advances from the first to fifth maturity stages (sour cherry, cv. 'Kütahya') (Aslantas et al. 2016)

fruit color, in the 1st maturity stage. The fruit mass and dimensions increased with increase in maturity stage. TSS and TA were highest in the 5th stage. The fruit detachment force decreased with increase in maturity stage. It was found that 3rd−5th maturity stages were very important for harvest and the maximum fruits should be in these stages to attain greater fruit yield per tree and color for the market.

Postharvest Handling and Technology

Sweet cherries are mainly destined for fresh market while as sour cherries are used for manufacture of various products. Cherries are highly perishable and have relatively short shelf life. They are susceptible to various physiological and microbiological disorders during storage and thus lead to huge losses. The aim of the postharvest handling and technology is to avoid or reduce these losses and involves several technologies, starting from choosing the right time for harvest, rapidly reducing fruit temperature, increasing relative humidity with the use of packaging materials, and keeping the cool chain during transport and marketing to assure high fruit quality upon arrival to the consumer (Zoffoli et al. 2017).

Controlling the storage temperature is very crucial for maintaining the fruit quality during storage. The temperature can be maintained by different cooling methods such as hydrocooling, forced air cooling and room cooling. The recommended temperature during storage and transport of cherries is 0 °C, while for harvesting and handling it is between 10 and 20 °C because this temperature range reduces the impact bruising damage (Crisosto et al. 1993). Relative humidity affects water loss from fruit surfaces as well as from stems and the optimum relative humidity for sweet cherries is 90-95 %. At optimum temperature, this relative humidity range maintains the stem color (Alonso and Alique 2006).

The important postharvest techniques used to improve the quality and shelf life of cherries are discussed below:

Controlled Atmosphere Storage

Controlled atmosphere (CA) with lower levels of oxygen and higher levels of carbon dioxide has been shown to increase the shelf life of cherries (Goliáš et al. 2007). Low oxygen and high carbon dioxide levels suppress the fruit respiration rate (Kupferman and Sanderson 2001) and also can affect other metabolic pathways (Goliáš et al. 2007). Therefore, the levels of CO_2 and O_2 must be carefully maintained as excess CO_2 or too low O_2 can lead to irreversible fruit injury and production of off-flavors and thus reduce their storage life (Chockchaisawasdee et al. 2016).

CA storage has shown many positive effects on sweet cherries. It helps to maintain the titratable acidity content, retard the decrease in SSC, retain the firmness,

stem color and brightness, and reduce the surface pitting and microbial spoilage (Serradilla et al. 2012). Sweet cherries can tolerate very low levels of oxygen (0.02% O_2 for 21-25 days) at low temperatures (0-5 °C), and thus can be stored for several weeks (Dangyang and Kader 1992; Golding et al. 2012). Several CA conditions have been investigated on cherries and it was reported that the application of CO_2 levels of 10-30% and O_2 levels of 5-20% effectively maintained the fruit firmness, vitamin C and TA levels without the production of off flavors (Wang and Vestrheim 2002; Tian et al. 2004).

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) has been successfully used to maintain the quality of cherries during storage and marketing (Wani et al. 2014). MAP maintains fruit firmness and color, preserves green stem color, prevents water loss and shriveling of fruit, and thus keeps the cherries in excellent condition (Kahlke et al. 2009). Depending on the cherry cultivar, different oxygen and carbon dioxide concentrations and combinations may be used in MAP of cherries (Padilla-Zakour et al. 2007). The success of MAP depends on the physical properties of the packaging film and the respiration rate of the product (Petracek et al. 2002). The physical properties of the film depend on the oxygen and carbon dioxide permeability while the respiration rate depends on harvest date, maturity, variety, and other factors.

The fruit packed in a properly designed MAP bag maintains red skin color similar to that at harvest and suppresses decay (Zoffoli et al. 2017). The gas composition inside the package may be changed to reduce the metabolic processes as well as microbial spoilage. Low O_2 reduced the respiration rate, and progressive reductions in O_2 concentrations less than 10% produce a logarithmic reduction in respiration rate. Fermentation or development of 'off-flavour' is the critical issue associated with commercial storage temperatures for sweet cherry under MAP. The fermentation induction points for 'Bing' and 'Sweetheart' have been estimated for 1 and 3–4% O_2 at 0 and 20 °C, respectively (Wang and Long 2014). Ethanol and acetaldehyde accumulate to significant levels when a low concentration of O_2 (1.5%) is combined with a high concentration of CO_2 (11.5-12%) (Goliáš et al. 2007). The accumulation of these compounds makes the cherries unacceptable during long term storage (Zoffoli et al. 2017).

Several authors have reported different gas combinations for different cherry varieties. Eris et al. (1993) suggested a gas combination of 5% CO_2 and 5% O_2 for cultivars like Napoleon, Karabour and Stella. For cultivars like Heldenfigen and Gemerdof, the optimum gas composition was 3% CO_2 and 3% O_2 (Ionescu et al. 1978). Remón et al. (2003) reported 20% CO_2 and 5% O_2 for Burtlat cherries while Chen et al. (1981) reported 0.03% CO_2 and 0.5–2% O_2 for Bing cherries. The optimum concentration for Sweetheart cherries was either 5% CO_2 and 10% O_2 or 4% CO_2 and 6% O_2 (Meheriuk et al. 1997). The gas combinations of 8% CO_2+ 5% O_2 and 10% CO_2+ 5% O_2 used in MAP of sweet cherries was effective in reducing rot-

ting, browning of peduncles, darkening of fruit colour and loss of fruit firmness and acidity in comparison to cherries packed in macro-perforated box liners (Crisosto et al. 2002).

The color of cherries was maintained well during 4 weeks of storage under MAP conditions (Wargo et al. 2003). This may be due to the increased anthocyanin content during storage under MAP conditions (Conte et al. 2009). MAP had a little or no effect on pH and TSS of cherries. However, some studies have reported that the pH values increased slightly due to the reduction in acidity values (Remón et al. 2003; Serrano et al. 2005). Remón et al. (2003) observed that TSS content of sweet cherries was not affected by MAP and remained stable during storage. MAP maintains the firmness of cherries and the fruits packed with 5% O_2 + 10% CO_2 showed higher firmness values (Tian et al. 2004). Also, gibberellic acid in combination with MAP resulted in higher firmness values in sweet cherries during storage (Usenik et al. 2008).

MAP has a significant effect on various enzymes. According to Tian et al. (2004), the enzyme activities of polyphenol oxidase and peroxidase were inhibited and malondialdehyde content was reduced by the gas composition of 10% CO_2 and 5% O_2 which led to a decrease in flesh browning. Wang et al. (2014a) also reported that the activity of these enzymes was affected by super atmospheric O_2 packaging. Özkaya et al. (2015) reported a decrease in polygalacturonase, polyphenol oxidase activities for "0900 Ziraat" sweet cherries stored under a combined treatment of cold chain and modified atmosphere–modified humidity packaging. Remón et al. (2003) reported that the activity of pectin methyl-esterase increased during storage.

Khorshidi et al. (2011) studied the effect of MAP (15% CO_2 +10% O_2 + 75% N_2) on sweet cherry cv. Siah-e-Mashhad and sour cherry cvs. Erdi Botermo and Albaloo Mohallai and reported that the fruits stored in MAP had better quality than those stored under normal atmosphere due to higher TSS, TA, firmness, and lower pH, TSS/TA ratio and weight loss. Wang et al. (2014a) studied the effect of super atmospheric O_2 packaging on cherry fruits and reported that super atmospheric O_2 packaging successfully delayed the respiration peak and significantly inhibited ethylene production during the first 4 days of storage. It also maintained the fruit firmness and soluble protein and sugar contents.

MAP not only modifies the gas composition inside the package due to respiration of the fruit but also increases the relative humidity around the fruit (Zoffoli et al. 2017) due to transpiration. The relative humidity inside the package increases to 90–95%. MAP allows the excess moisture to escape and thus maintains some humidity know as modified humidity inside the package (Özkaya et al. 2015). The combined effects of fast cold chain and modified atmosphere–modified humidity packaging on early-harvested "0900 Ziraat" sweet cherries were studied by Özkaya et al. (2015) and reported that this combined treatment reduced the weight losses, pitting amount, stem color and maintained the initial fruit quality better than the controls during storage.

Irradiation

Irradiation has been recognized as an alternative to chemicals for treating fresh and dried agricultural products to overcome quarantine barriers in international trade, as a mode of decontamination, disinfestations, delaying the ripening and senescence of fruits and vegetables, and for improving nutritional attributes and shelf life (McDonald et al. 2012; Hong et al. 2008; Lacroix and Ouattara 2000). Irradiation of food and agricultural products is one of the most reliable and safest methods used for preservation and improvement of nutritional value and safety of these products. It is a safe alternative to chemical treatments and has been used to overcome quarantine and trade-related barriers in the international trade (McDonald et al. 2012; Hong et al. 2008; Lacroix and Ouattara 2000). Several studies have been conducted on cherry fruit to maintain its quality and shelf life extension.

Drake and Neven (1997) used electron beam irradiation at different doses (0.00, 0.15, 0.30, 0.60 and 0.90 kGy) on 'Bing ' and 'Rainier' sweet cherries and reported that soluble solids, titratable acidity and flavor were not affected by these irradiation doses. Irradiation doses above 0.60 kGy resulted in increase in defects in 'Rainier' cherries while as defects in 'Bing' cherries were unaffected at all irradiation doses. The objective color of 'Rainier' cherries was decreased at irradiation doses of 0.60 kGy and above while the color of 'Bing' cherries was increased at higher doses than 0.30 kGy. The stem color of 'Rainier' cherries was increased above 0.60 kGy while the stem color of 'Bing' cherries remained unaffected. Irradiation doses of 0.60 kGy and above led to a decrease in firmness values for both the types of cherries.

Akbudak et al. (2008) studied the effect of gamma irradiation on sweet cherry cv. "0900 Ziraat" under different controlled atmospheres, stored for up to 60 days after irradiation and reported that the cherries stored under normal atmosphere showed higher weight loss compared to the cherries under controlled atmosphere. Higher firmness values and less spoilage were observed in irradiated samples than non-irradiated ones. The combined effect of controlled atmosphere (20% CO_2:5% O_2, 25% CO_2:5% O_2) and gamma irradiation resulted in the highest acidity and ascorbic acid values.

Parveen et al. (2015) investigated the effect of gamma irradiation on quality and shelf-life of two cherry varieties (Misri and Double). These fruits were irradiated with different doses (0.3 -1.5 kGy) and stored under ambient and refrigerated conditions. Higher irradiation doses (1.2 and 1.5 kGy) were effective in maintaining the fruit quality and delaying the decay of the cherry varieties. Irradiation doses of 1.2 and 1.5 kGy effectively delayed the decay process of cherries up to 9 days at ambient conditions and up to 28 days at refrigerated conditions. The firmness values were higher for cherries irradiated 1.2 kGy than those of irradiated at 1.5 kGy.

Hussain et al. (2016) investigated the effect of gamma irradiation on carboxymethyl cellulose (CMC) coated cherries. Two cherry varieties (Misri and Double) harvested at commercial maturity were coated with CMC (0.5–1.0 % w/v) and gamma irradiated at 1.2 kGy and stored under ambient and refrigerated conditions. CMC coatings alone at concentrations of 0.5 and 0.75 % showed no inhibitory

effect on mold growth under both storage conditions while the coating at 1.0 % w/v delayed the mold growth upto 5 days under ambient conditions. Also, irradiation dose of 1.2 kGy irradiation delayed mold growth up to 8 days under ambient conditions. All the concentrations of CMC coating in combination with irradiation were effective in maintaining the quality and delaying the decay process of cherry fruit during post-refrigerated storage. However, the combination of CMC at 1.0 % w/v and 1.2 kGy irradiation gave the best results in comparison to all other treatments.

Thang et al. (2016) compared the effect of gamma irradiation (0.4 kGy) and methyl bromide fumigation on various quality characteristics 'Sweetheart' cherries (*Prunus avium*) and reported that irradiation resulted in an immediate decline in firmness values without further significant change during storage while fumigation resulted in 11-14% decrease in firmness during storage. Fumigation did not affect the cherry quality characteristics initially; however, during storage, it led to greater damage and mold growth than the control and irradiated samples. Irradiation at 0.4 kGy reduced the *Salmonella* spp. and *Listeria monocytogenes* counts by approximately by 1 log CFU g^{-1}. This irradiation dose had no negative effect on cherry quality and thus can be used as an alternative to methyl bromide fumigation.

Edible Coatings

Edible films and coatings are thin layers of packaging material and prepared from edible products (Hassan et al. 2017). Edible coatings have the potential to increase shelf life, improve safety of food and product quality and fulfill consumer demands (Mostafavi et al. 2015). Hence, edible coatings have the ability to control moisture transfer, respiration rate and oxidation processes (Dhall, 2013). Several types of coating materials such as alginate, chitosan, almond gum, gum Arabic, whey protein isolate and *Aloe vera* gel, have been used for sweet cherry preservation (Aday and Caner 2010; Dang et al. 2010; Mahfoudhi and Hamdi 2014).

Chitosan-based coatings are widely used in food preservation because of their excellent film forming capability (Chong et al. 2015), antimicrobial activity (Lei et al. 2014; Shankar et al. 2015) and safety for human consumption. These coatings have been used to increase the shelf life of several fruits like sweet cherry, berries, pear and carambola (Xin et al. 2017). Pasquariello et al. (2015) investigated the effect of chitosan coating (0.5%) on senescence and antioxidant enzymes of different sweet cherry cultivars ("Ferrovia", "Lapins", and "Della Recca") and reported that chitosan coating increased the activity of some antioxidant enzymes, including superoxide dismutase and ascorbate peroxidase. This coating repressed polyphenol oxidase and guaiacol peroxidase activities and thus, prevented flesh-browning and extended storage life of sweet cherries. Also, chitosan coating maintained membrane integrity by decreasing lipoxygenase activity and malondialdehyde accumulation. Chitosan coating resulted in a reduced decay both at 2 °C and 24 °C than the control fruits.

Xin et al. (2017) reported that the chitosan-based coatings efficiently decreased postharvest ripening parameters including in Chinese cherry during storage. A combined chitosan and nano-SiOx coating was most effective treatment leading to decrease in weight loss and decay rate, increase in firmness, and less changes in SSC and TA content than the control sample. This treatment maintained a higher content of sodium carbonate-soluble pectin, and prevented pectin chain degradation.

Romanazzi et al. (2003) studied the effect of chitosan and short hypobaric treatments, alone or in combination, on storage decay of sweet cherries for over 2 years. For both the years, chitosan and hypobaric treatments applied individually led to a decrease in various rots. A combination of 1.0% chitosan and 0.50 atm was reported as the best treatment for controlling decay of sweet cherries.

Yaman and Bayoindirli (2002) investigated the effects of Semperfresh™ (edible coating) and storage on quality and shelf-life of cherries. After harvest, the cherries were treated with two different concentrations of Semperfresh™ (10 and 20 g L^{-1}) coatings and stored under two different temperatures (30±3 °C, 40–50% relative humidity and 0 °C, 95–98% relative humidity). Results revealed that Semperfresh™ effectively decreased the weight loss and increased the fruit firmness, ascorbic acid content, TA and skin color of cherries during storage. Coating treatment showed no effect on SSC and sugar content of the cherries. Semperfresh™ improved the shelf-life of the cherries by 21% and 26 % at 30±3 °C and 0 °C, respectively, without noticeable quality losses.

According to Martinez-Romero et al. (2006) an edible coating based on *Aloe vera* gel, applied on sweet cherries decreased respiration rate, rapid weight loss, colour changes, softening, ripening, stem browning and microbial counts compared to control during storage. The sensory attributes were improved by using the *Aloe vera* based edible coating. Dong and Wang (2018) studied the effect of guar gum and ginseng extract coatings on various quality parameters during storage of sweet cherries and reported that guar gum-ginseng extract coatings controlled water loss and delayed loss of firmness and of titratable acid, ascorbic acid and total phenols, compared with untreated cherries.

Chemical Treatments

1-Methylcyclopropene

1-Methylcyclopropene (1-MCP) is a cyclic olefinic compound and act as ethylene action inhibitor. It regulates the response of plant tissues to ethylene by blocking the ethylene receptors, and preventing them from binding with ethylene. The effect of 1-MCP has been investigated less on non-climacteric than on climacteric fruits and showed different responses towards 1-MCP treatment (Mozetič et al. 2006). This difference in behavior towards 1-MCP may be due to difference in their ethylene receptors (McGlasson 1985) and their regulatory functions (Tian et al. 2000).

Gong et al. (2002) investigated the effect of 1-MCP on two sweet cherries cultivars (Bing and Rainier) and reported that 1-MCP at three concentrations (0.1, 1 and 10 μL L^{-1}) had no effect on color change and steam browning during storage. Mozetič et al. (2006) investigated the effect of 1-MCP at different concentrations (0, 180 and 360 nL L^{-1}) on sweet cherry cv. Lambert Compact stored at 2–4 °C and reported that 1-MCP did not decrease the color change but reduced the cherry rot at a concentration of 360 nL L^{-1}. Also, the 1-MCP treatment had no effect on anthocyanins and hydroxycinnamic acids in sweet cherry.

Sharma et al. (2010) reported that the postharvest treatment of hexanal vapour and 1-MCP, alone or in combination, increased the firmness of cherries and enhanced the activities of superoxide dismutase and ascorbate peroxidase. The anthocyanins and phenolic contents either increased or remained constant during the storage period.

Yang et al. (2011) investigated the effect of 1-MCP on sweet cherries and reported that postharvest treatments of 1-MCP decreased the endogenous ethylene production, malondialdehyde content and polyphenol oxidase activity in cherry fruits after cold storage in comparison to untreated fruits. 1-MCP treatment resulted in lower respiration rate and relative electric conductivity and helped in maintaining cell membrane integrity. This treatment effectively inhibited the declining activity of peroxidase and catalase.

Calcium Chloride

Calcium treatment has high commercial potential for increasing the nutritional quality of fruits (Aghdam et al. 2013). This treatment can increase nutritional quality during postharvest life and enhance shelf life by maintaining fruit firmness, decreasing respiration rate, ethylene production, decay and browning, increasing aroma biosynthesis, delaying fruit ripening, and preventing chilling injury (Martin-Diana et al. 2007). Postharvest treatment of calcium may decrease the senescence during storage, without negative effect on consumer acceptance (Lester and Grusak 2000).

Aghdam et al. (2013) studied the effect of calcium chloride on antioxidant property of cornelian cherry fruits and reported that the calcium chloride treatments effectively maintained higher levels of total phenols, flavonoids, anthocyanins, ascorbic acid contents and DPPH scavenging activity. Also, the phenylalanine ammonialyase activity was enhanced by calcium chloride treatments.

Wang et al. (2014b) investigated the effect of calcium chloride on two sweet cherries cultivars (‘Lapins’ and ‘Sweetheart’). The results revealed that the fruit tissue calcium content increased logarithmically for ‘Sweetheart’ and linearly for ‘Lapins’ with the increase in calcium chloride rate. The respiration rate, ascorbic acid degradation, and membrane lipid peroxidation decreased, which increased total phenolics content and total antioxidant capacity. The fruit firmness and pitting resistance increased but titratable acidity loss and decay

decreased in both cultivars. Lower concentrations of calcium chloride (0.2 and 0.5 %) inhibited the pedicel browning while as the higher concentrations (1.0 and 2.0 %) increased the browning of pedicel. This may be due to the modification of membrane lipid peroxidation.

Processing of Cherry

Dehydration

For drying process, fully ripened cherries are used. Cherries are dried to maintain color and flavor, inactivate enzyme and increase the shelf life. Drying removes the moisture content of cherries and thus makes shipping, baking, and other uses easy (Maltini et al. 1993). Drying can be done for both sweet and sour cherries. A number of dried or semi-dried cherry products are produced and marketed, including whole fruit without stones, as raisins or infused fruit as snacks, smaller fruit parts as ingredients, candied fruit and gums, and dried fruit powders (Jensen 2017). Cherry "raisins", a specialty product of Washington State, are prepared by drying Rainier and Bing cherries (Kaack et al. 1996; McLellan and Padilla-Zakour 2004). Drying of cherrires results in a typical flavor, a chewy texture and a decrease in moisture content (25 %). Dried cherries find wide applications in pastry, confectionery products, ice cream, frozen desserts, sweets, fruit salad, cheese and yogurt products.

Freezing

Freezing is an efficient way to preserve fruits for a long time. Both the sweet and sour cherries are being preserved using freezing technique. Freezing results in better color, improved flavor and firmer texture of cherries than canning process. Thus, frozen cherries are widely used by the baking and other associated industries which require high-quality cherries based on a convenience and availability throughout the year (McLellan and Padilla-Zakour 2004).

Individual quick freezing (IQF) is also used for cherry preservation. In this process the individual fruit is frozen by blowing cold air up through a slowly running mesh conveyor belt in a fluid bed system that continuously moves the fruit, thereby preventing the fruit from clumping together during freezing (Barbosa-Canovas et al. 2005). During the first part of the freezing, only single layers of fruit are frozen to quickly freeze the surface. Later, full freezing can be done in thicker layers. Frozen fruit are packed in airtight plastic bags and kept frozen at –18 to –23 °C. Flushing fruit with gases from liquid CO_2 or liquid nitrogen may give faster freezing of IQF fruit (Jensen 2017).

Canning

Canning is a traditional method of cherry preservation. Canning of sweet and sour cherry fruit is used to provide long preservation of whole or parts of fruit that are easy to apply as ingredients in other foods or as part of pastries or ready-to-eat desserts (Jensen 2017). In the United States alone, about 30 % of the sour cherries and 12 % of the sweet cherries are preserved by canning (McLellan and Padilla-Zakour 2004). Fresh fruit are washed, sorted for damaged fruit, the pedicels removed, and in most cases, the pits removed. Fruit is filled into cans/glasses and then hot syrup from 16–45°Brix is added, filling the can (Kaack et al. 1996). Some products use concentrated sour cherry juice with high Brix as filling to optimize flavour. For use in pastries, sour cherries are supplemented with starch filling. After filling, the headspace air is exhausted and the can is sealed and thermally processed for pasteurization as fast as possible and immediately cooled to avoid heat damage to the product (Chaovanalikit and Wrolstad 2004).

Cherry juice processing

Sweet cherry as well as sour cherry is used to produce juice. It can be prepared from both fresh and frozen stored cherries. Cultivars with a high juice content and low firmness, high sugar and medium to high colour content, and medium to high total acidity are preferred for juice production. A good balance between sugar content and acidity and a positive sensory profile is considered to be very important for high sensory quality (Clausen et al. 2011). The juice preparation is done by two methods-hot extraction and cold extraction methods. These two methods produce reasonable quality products but still some additional techniques such as clarification and filtration are required to produce high quality fruit juice (Horvath-Kerkai 2006). Cherry juice can be further processed into nectars, concentrates or powders. For production of nectars, sucrose syrup solutions are normally added to the juice or concentrate (Toydemir et al. 2013). Production of cherry concentrates can be done by several methods, including evaporating by heating, vacuum drying, freezedrying, cryoconcentration, membrane filtration, reverse osmosis and spray drying (Aider and de Halleux 2008). Cherry juice powders have been produced using different drying methods (McLellan and Padilla-Zakour 2004).

Postharvest Disorders

The main postharvest disorders of sweet cherry are moisture loss (dehydration), colour changes, softening, surface pitting, stem browning and loss of acidity (Bernalte et al. 2003). Postharvest water loss occurs both from the fruit and from the

pedicel (stem), with pedicel loss being most evident and thus affects the consumer acceptability. High temperature and low humidity are the main factors leading to the postharvest water loss from cherries. Thus, fruit dehydration can be minimized by lowering fruit temperature quickly after harvest and increasing the humidity around the product (Zoffoli et al. 2017).

Fruit firmness is an important quality parameter of cherries. Firmness not only influences eating quality, but also affects storage performance. Loss in firmness leads to a disorder known as softening. The middle lamellae and primary cell walls are subject to structural changes during ripening, which lead to cell separation and tissue softening. During softening, an increase in the content of soluble pectin polysaccharides is observed (Bartley and Knee 1982).

Surface pitting of cherries occurs due to both compression and impact forces during harvesting, sorting, packaging and processing (Zoffoli et al. 2017). Pitting affects not only the cherry appearance but also shortens shelf life and reduces market value. Severe pitting leads to increased respiration, premature decay and softening during storage (Mitchell et al. 1980).

Postharvest microbial spoilage usually occurs due to pre-harvest infections. These infections start through the wounds in the fruit skin and increase further during post handling and storage. The main causes of pre- and postharvest spoilage in sweet cherries are brown rot and grey mould caused by *Monilinia* spp. and *Botrytis cinerea*, respectively (Adaskaveg et al. 2000). They also suffer from *Rhizopus* rot, blue mould, *Alternaria* rot and *Cladosporium* rot caused by *Rhizopus stolonifer*, *Pencillium expansum*, *Alternaria alternata* and *Cladosporium* sp. (Romanazzi et al. 2009). *Pseudomonas syringae* is responsible for bacterial canker disease in cherries (Bright and Marte 2004). The control of these spoilage microorganisms can be achieved through the use of synthetic or natural antimicrobial compounds. Sweet cherry fruit has a unique property to tolerance higher levels of CO_2 concentrations than other stone fruits (Wang and Vestrheim 2002) and thus, high CO_2 levels can be used to prevent decay by many fungi (DeVries-Patterson et al. 1991).

Conclusion

Cherries are non climacteric fruits cultivated in the temperate regions of the world and include sweet and sour cherries. Sweet cherries are mainly consumed as a fresh while as sour cherries are used for manufacture of various products. Cherries are highly perishable and susceptible to various physiological and microbial disorders and hence several processing technologies have been developed to increase the shelf life and market value of cherries. These include CA storage, MAP, irradiation, edible coatings, chemical treatments, dehydration, freezing, canning and juice processing.

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Postharvest Biology and Technology of Peach

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Introduction

Peach (*Prunus persica* (L.) Batsch) belongs to the family Rosaceae and is native to China (Lurie and Crisosto 2005). The Chinese literature dates its cultivation in China to 1000 BC (Crisosto and Valero 2008). Once, peach was called Persian apple and it was probably carried from China to Persia (Iran) and, thus, peach quickly spread from there to Europe (Lurie and Crisosto 2005). Currently, the world production of peaches stands at 21.2 million tons and the largest producer of peach fruit is China, followed by the United States, Italy, Turkey, Chile, Japan, Australia, and Russia (USDA 2017). Peach is the third most important deciduous fruit crop in the world (Llácer et al. 2009) and the second most important in the European Union, after apple. Spain is the second largest producer in the European Union, after Italy, with 29% of the total production (Europêch 2011).

Peaches are characteristically soft-fleshed and highly perishable fruit, having limited market life. A peach fruit contains approximately 87% water with 43 kcal of energy per 100 g of fruit. It contains carbohydrates, organic acids, pigments, vitamins, volatiles, antioxidants, and trace amounts of proteins and lipids, which make it very attractive to consumers (Crisosto and Valero 2008). It is rich in ascorbic acid (vitamin C), carotenoids (provitamin A), and phenolic compounds that act as

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natural antioxidants (Tomás-Barberán et al. 2001; Byrne 2002). They are highly perishable climacteric fruit and would suffer rapid ripening and deterioration after postharvest, and, thus, have a limited postharvest life at room temperature. During storage time, peach fruit may undergo softening and rotting, which largely cause loss of quality (Razavi and Hajilou 2016). According to Crisosto et al. (2008), peaches with flesh firmness between 9 and 13 Newtons are considered as being at the 'ready-to-eat' stage. Below these values, the fruit could be considered as being in the overripe stage, hence commercially unmarketable.

To improve the storage life and postharvest nutritional quality, and retard metabolic changes which deteriorate peach fruits quickly at ambient temperature after harvest, cold storage is widely used (Girardi et al. 2005). However, peach fruit succumbs to chilling injury within 1–2 weeks when stored at 2–5 °C (Lurie and Crisosto 2005). Chilling injury is characterized by internal browning, mealiness, juicelessness, failure to ripen normally, leatheriness, and other imperfections which are related to cell wall integrity and pectin metabolism (Lurie and Crisosto 2005). Several other techniques used to improve the shelf life of peach are controlled atmosphere storage, modified atmosphere packaging, heat treatment, intermittent warming, chemical treatments, irradiation, and use of nanocomposite packaging material and edible coatings.

Peach fruits are susceptible to attack of phytopathogenic fungi such as *Monilinia laxa*, *Monilinia fructicola* (responsible for brown rot) (Mari et al. 2008), and *Rhizopus stolonifer* (responsible for *Rhizopus* rot) (Salem et al. 2016). These molds are the leading causes of postharvest decay in fully mature and ripe peaches. Thus, control of mold disease is especially important during storage because it develops at both low as well as high temperatures (1–2 °C for gray mold; above 15 °C for black mold) and spreads quickly among fruits (Karabulut et al. 2004). The losses due to fungal decay can be reduced by using synthetic fungicides which can ensure product protection. But the negative impact of these synthetic fungicide residues on human health and the environment has promoted deregulation and restricted use of key chemical fungicides throughout the world (Cetinkaya et al. 2006). Apart from this, the use of gamma irradiation (Kim et al. 2010) and heat treatment (Spadoni et al. 2014) were effective methods to inactivate fungal rots in peaches.

Nutritional Composition

Peach is a good source of ascorbic acid (vitamin C), carotenoids, and phenolic compounds that act as natural antioxidants (Tomás-Barberán et al. 2001; Byrne 2002). The ascorbic acid content of various cultivars of California peach ranged from 6 to 9 mg/100 g in white flesh and from 4 to 13 mg/100 g in yellow flesh (Gil et al. 2002). In another study, the ascorbic acid content of 5–6 mg/100 g in European peach cultivars was observed (Carbonaro et al. 2002).Gil et al. (2002) reported that the total carotenoids concentration was in the range of 71–210 mg/100 g fresh weight for yellow-fleshed and 7–20 mg/100 g for white-fleshed peach cultivars. The main carotenoid detected was β-carotene (provitamin A), but small quantities of α-carotene and β-cryptoxanthin are also present in some peach cultivars.

Fruit phenolics have a role in fruit color, taste, and health beneficial property (Tomás-Barberán et al. 2001). The total phenolics concentration expressed as mg/100 g fresh weight varied from 28 to 111 for white-fleshed and from 21 to 61 mg/100 g of fresh fruit for yellow-fleshed California cultivars (Gil et al. 2002). Other European cultivars had values of 38 mg/100 g (Proteggente et al. 2002), while the Spanish cultivar 'Caterina' showed values of 240 and 470 mg/100 g for pulp and peel, respectively (Goristein et al. 2002). Belhadj et al. (2016) reported that the Chatos variety of peach showed the highest content in the first stage of maturation (around 36.4 mg GAE/g FW) compared with the Elegant Lady variety of peach, which presented 18.37 mg GAE/g FW. It was further reported that the Chatos variety of peach showed the highest content of flavonoids during the first stage of maturation (around 1.22 mg RE/g FW) in comparison with the Gladys variety at the same stage, which was 0.51 mg RE/g FW. The higher concentrations of flavonoid compounds in the first stage of maturation as compared to stages 2 and 3 could be explained by the condensation of different phenolic acids during later stages of maturation, then forming complex phenolic compounds such as tannins and lignin (Ahmed et al. 2009).

Peach fruit accumulates different types of soluble sugars and sugar alcohols, mainly sucrose, glucose, fructose, and sorbitol. Sucrose is the predominant sugar in the peach mesocarp at maturity, accounting for approximately 40–85% of the total sugar content, followed by glucose and fructose, together representing approximately 10–25%, and sorbitol accounting for less than 10%. Sucrose, glucose, and fructose represent about 75% of peach fruit soluble sugars (Crisosto and Valero 2008; Cirilli et al. 2016). The total sugar content increases continuously during peach development up to full maturity, remaining constant or slightly decreasing during postharvest storage (Borsani et al. 2009). Hexoses are the most abundant sugars in immature peach fruit until the beginning of rapid growth by cell elongation, when sucrose becomes the predominant type (Vizzotto et al. 1996; Zanon et al. 2015).

Minerals in peach fruits include macroelements (K, Mg, and Ca) and microelements (Mn, Fe, Cu, and Zn). Iordănescu et al. (2015) while studying the minerals in peach cultivars belonging to the world germplasm collection in the conditions of west Romania, reported that the K content varies between 97.0 mg/100 g FW in the Giala di Roma cultivar and 106.0 mg/100 g FW found in Springold cultivar. In terms of microelement content, iron represents the principal element in the analyzed samples. The Fe content varies between 0.250 mg/100 g FW in the Poli and 0.480 mg/100 g FW in the July Elberta cultivars. The highest Zn content was recorded in the Piros Magdalena and Eureka cultivars (1.84 and 1.80 mg/100 g FW, respectively). Cu and Mn were detected in lower quantities in peach cultivars and hybrids.

Maturity

Maturity is the starting point of postharvest quality management. Therefore, it must be ensured that properly matured fruits should be harvested (Ahmad and Siddiqui 2015). At which stage of maturity a fruit should be harvested is crucial to its subsequent storage, marketable life, and quality. Maturity always has a considerable

influence on the quality of fresh produce as well as the storage potential and occurrence of many storage disorders (Siddiqui and Dhua 2010).

Maturity stage at harvest has been described as a key factor affecting fruit quality (Infante et al. 2012), but this is difficult to determine since flesh firmness (Remorini et al. 2008) and ground skin color, among other parameters described to determine fruit ripeness, do not evolve coordinately during stone fruit maturation (Infante et al. 2008). Many studies have investigated the peach maturity level using destructive or non-destructive methods (Herrero-Langreo et al. 2012; Zhang et al. 2017). Among these non-destructive approaches, visible/near-infrared spectroscopy seems particularly promising, since it provides fast and reliable information on the internal characteristics of many fruit species (Farneti et al. 2015). Nascimento et al. (2016) used near-infrared spectroscopy to investigate peach maturity predictions by the partial least squares model of the soluble solids content and fruit firmness in low chilling peach. They created prediction models for soluble solids content and fruit firmness, and established the optimization potential of the model. Matteoli et al. (2015) proposed a spectral-based non-destructive method for the classification of peach maturity levels that estimates the firmness of the flesh to classify the maturity level by the reflectance spectra. They used multiple retrieval techniques and the fuzzy classification system, and this method lays the foundation for the automatic classification of peach fruit maturity.

The index of absorbance difference (I_{AD}) is an indicator that is based on the close relationship between the degradation of chlorophyll and the maturity of the fruit, which is determined by the difference between the absorption using near-infrared spectroscopy. It directly reflects the actual content of chlorophyll a (Ziosi et al. 2008). The non-destructive measurement of I_{AD} is not harmful to fruit, the reading is fast, convenient, and it is more desired than the destructive assays, such as firmness and soluble solids content. Therefore, it is highly suitable for fruit quality estimation at the end of the supply chain. Currently, I_{AD} predication is carried out mostly on stone fruit trees, such as peach (Shinya et al. 2013) and plum (Infante et al. 2011). Lurie et al. (2013) collected the I_{AD} at harvest of both early- and late-maturity peach varieties, carried out a non-linear regression analysis of the change in firmness during shelf time, and established the logistic model of firmness change. They used time resolution reflectance spectroscopy to evaluate the degree of maturity and believed that the measurement of I_{AD} at harvest might classify the fruits into various categories based their potential shelf time, which may ensure better fruit quality.

During the maturation of peach fruit, the internal soluble solids content rises, firmness declines (Dabbou et al. 2016; Spadoni et al. 2016), red color appearance increases, and the green color in the pericarp fades (Zhang et al. 2015). Zhang et al. (2017) reported that peach (Xiahui 8 variety) had relatively high soluble solids content, a^* and a^*/b^* values, and a low fruit firmness at maturity degree II, which indicated that the I_{AD} for degree II fruit was lower than that for degree I fruit. The a^*/b^* value can reflect the true color of the fruit (Rodrigo and Zacarias 2007) and was higher in the degree II fruit than in degree I peach of variety Xiahui 8 (Zhang et al. 2017). This is consistent with the opposite change in I_{AD}, which indicated that the pericarp I_{AD} value is closely related to the color of the pericarp. A significant differ-

ence in pericarp color, I_{AD} value, and most quality indicators was seen in the fruits at the different maturity degree points. This suggested that light absorption and scattering are the main impacting factors on I_{AD}, which will further affect the pericarp pigment and the change in fruit texture (Zerbini et al. 2006; Muhua et al. 2007; Ziosi et al. 2008).

Fruit Ripening

The postharvest lifetime of fruits can vary from days to several months, and is dependent on a multiplicity of internal and external factors (Tian et al. 2013). The ripening of peach fruit involves many biochemical and physiological processes, such as the degradation of chlorophyll and starch, the biosynthesis of pigments and volatile compounds, the accumulation of sugars and organic acids, as well as the modifications of the structure and composition of cell wall polysaccharides (Giovannoni 2001;Goulao and Olivera 2008). Once ripeness has been reached, the texture of the mesocarp continues to change and soften and, thus, the firmness of the fruit is rapidly lost (Brummell 2006).

The ripening process and fruit genotype are considered as fundamental factors that affect the biosynthesis of phytochemicals. The ripening and respiratory climacteric response are closely associated and are characterized by a burst of respiration that follows a response to ethylene production (Dangl et al. 2000). Peaches can be classified as climacteric fruit according to the patterns of respiration and ethylene evolution, which is a consequence of a dramatic increase in the levels of 1-aminocy clopropane-1-carboxylic acid synthase and1-aminocyclopropane-1-carboxylic acid oxidase, the two enzymes of the biosynthetic pathway (Ruperti et al. 1998, 2001; Giovannoni 2001; Prasanna et al. 2007). This ethylene production plays a key role in peach fruit ripening by coordinating the expression of ripening-related genes responsible for flesh softening, color development, and sugar accumulation, as well as other processes, such as abscission (Ruperti et al. 2002;Trainotti et al. 2006).

The ethylene produced in the early stage of peach fruit ripening indicated it to be a predictor of fruit ripening (Tonutti et al. 1997). However, in some late-maturing cultivars, the time point of respiration peak coincides with that of the peak of ethylene production (Ferrer et al. 2005). In some other cultivars, the peak of ethylene production occurs after the peak of respiration. These differences might be due to the different physiological processes in different fruit cultivars (Huan et al. 2016).

The development and ripening of climacteric fruits are oxidative processes, producing reactive oxygen species (ROS), such as superoxide radical (O_2^-) and hydrogen peroxide (H_2O_2) (Pandey et al. 2013). Huan et al. (2016) reported the roles of ROS as both toxic byproducts and as signaling molecules in fruit development and ripening. Superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPX) play important roles in balancing the induction and removal of ROS in plants, and are respectively encoded by families of closely homologous genes. The experimental results indicated that O_2^- and H_2O_2 acted as potential signaling mole-

cules in the middle stage of fruit development, and only H_2O_2 might function as a main toxic molecule to stimulate lipid peroxidation and oxidative stress in the late stage of fruit ripening. *PpaCu/Zn-SODs* were the most abundant members in the *PpaSOD* gene family and they expressed steadily in peach fruit development and ripening. Low temperature (4 °C) postponed and suppressed the climacteric peaks of respiration and ethylene, significantly enhanced the activities of CAT and GPX, and upregulated the expression of *PpaCAT1* and *PpaGPX6* in the late stage of fruit ripening. *PpaCAT1* and *PpaGPX6* were two key genes in alleviating oxidative stress in the late stage of fruit ripening.

The softening and textural changes that occur during fruit ripening are characteristic of particular species, and are due to differences in cell wall thickness and composition, cell size, shape, packing, contents, and turgor (Harker et al. 1997). Modification of the cell wall is believed to underlie changes in firmness and texture, but the type and magnitude of the alterations carried out during ripening vary considerably (Brummell et al. 2004). According to their texture at full ripening, two groups for the classification of peach fruit are melting flesh and non-melting flesh. When fully ripe, the flesh of melting flesh fruit is soft, juicy, and, therefore, extremely susceptible to handling and physical injuries, whilst non-melting flesh fruit remain firm even when fully ripe and soften slowly when overripe but never melt (Bassi and Monet 2008). Polygalacturonase is one of the pectin-degrading enzymes and plays a central role in the ripening process (Wakabayashi 2000). Ripening-related *exo*-polygalacturonase activity is found in both melting and non-melting peach, but *endo*-polygalacturonase activity accumulates only in ripening melting varieties, coincident with the melting phase (Orr and Brady 1993). The lack of a melting phase in non-melting peach varieties appears to be either due to a deletion of *endo*-polygalacturonase genes or to a truncation of their mRNAs, which causes an absence of immunodetectable *endo*-polygalacturonase protein (Callahan et al. 2004). Thus, *endo*-polygalacturonase-mediated pectin modification may play an important role in the later stages of softening and textural changes in melting flesh peach (Brummell et al. 2004).

Cold Storage

Peaches are highly perishable climacteric fruit and would suffer rapid ripening and deterioration after postharvest, and, thus, have a limited postharvest life at room temperature. Every year, harvesting season falls during a fixed period for 2–3 months (Ahmad and Siddiqui 2015). An increase in the shelf life of peach fruits would help the growers to supply their produce according to the market demand and fetch them better prices, and also make the fruits available to the consumers over an extended period of time (Pongener et al. 2011). Nowadays, low temperature is the most commonly applied method to extend postharvest life and maintain the quality of peach fruits (Razavi and Hajilou 2016).

Cold storage is among the methods used to extend the postharvest life of peach fruits (Lurie and Crisosto 2005). The peach fruits have a shelf life of 2–3 days under ambient conditions and about 2 weeks under cold storage conditions (Kader 2001). According to de Souza et al. (2009), refrigerated storage slows the plant metabolism by decreasing the respiratory rate and enzymatic activity. Cold storage at 4 °C induced greater ethylene production and 1-aminocyclopropane-1-carboxylic acid oxidase activity, accompanied by greater firmness loss in all peach cultivars except for the stony-hard phenotype cultivars (Giné-Bordonaba et al. 2016). Peaches are sensitive to low temperature, which can cause physiological disorders of fruit flesh, usually called chill damage or chilling injury, during cold storage (Jin et al. 2009a). Chilling injury develops more rapidly and severely when fruits are stored at temperatures between 2.2 and 7.6 °C than those stored at 0 °C (Crisosto et al. 1999). Therefore, the maximum storage life of peach fruit can be achieved near or below 0 °C (Lurie and Crisosto 2005).

Controlled Atmosphere Storage

Controlled atmosphere (CA) storage is a system of the storage of fresh produce in an atmosphere that differs from normal atmosphere in respect to CO_2 and O_2 levels. CA storage of peaches with elevated CO_2 and reduced O_2 concentrations delayed or prevented the appearance of mealiness, internal reddening, and flesh browning (Lurie and Crisosto 2005), and maintained the high quality of produce, including firmness (Fernández-Trujillo et al. 2000). In a study carried out by Yang et al. (2006), the investigators reported that yellow peaches were stored under controlled atmospheres of 2% O_2 + 5% CO_2, 5% O_2 + 10% CO_2, 2% O_2 + 10% CO_2, and 5% O_2 + 5% CO_2, with normal atmosphere at 2 °C, to investigate the effect of different concentrations of O_2 and CO_2 on the structure of a single sodium carbonate soluble pectin molecule. The microstructure changes, including aggregates and branches, were studied by atomic force microscopy on, initially, the 15th and 45th days. The microstructure of sodium carbonate soluble pectin molecules and polymers showed that aggregates separated gradually with the storage time. The degradation took place in the linear backbone as well as in side chains. The degradation of sodium carbonate soluble pectin molecules was inhibited by lower O_2 and higher CO_2 concentrations.

de Santana et al. (2011a) reported that the use of controlled atmosphere with elevated CO_2 and reduced O_2 concentrations prevented the onset of the chilling symptoms. Thus, the effects of three different conditions of controlled atmosphere (CA1, CA2, CA3, and control) were evaluated in order to extend the storage life of 'Douradão' peaches. After 14, 21, and 28 days, samples were withdrawn from CA and kept in fresh air at 25 ± 1 °C and 90 ± 5% RH to complete ripening. On the day of removal and after 4 days, the peaches quality characteristics were evaluated. The results showed that the use of CA during cold storage reduced weight loss and prevented postharvest decay. CA2 (5.0 kPa CO_2 and 1.5 kPa O_2) and CA3 (10.0 kPa

CO_2 and 1.5 kPa O_2) treatments were effective in keeping the good quality of 'Douradão' peaches during 28 days of cold storage; the ripe fruits showed reduced incidence of woolliness, and adequate juiciness and flesh firmness. CA1 (3.0 kPa CO_2 and 1.5 kPa O_2) and control treatments (fresh air: 0.03 kPa CO_2 and 20.9 kPa O_2) did not present marketable conditions after 14 days of cold storage.

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) techniques have been applied to extend the shelf life of peaches because of the resulting reduction in injuries caused by low temperatures (Crisosto and Valero 2008). MAP of peaches slowed down the respiration rate and retarded the decrease in titratable acidity values, maintained the fruit sugar, flesh firmness, total soluble solids, vitamin C, and fruit juice contents, and slowed deterioration through decreasing fruit injury and browning rates (Oliveira et al. 2015).

Fernández-Trujillo et al. (1998) reported that firm-breaker and firm-mature flat peaches were stored in air for 10 days at 20 °C, or precooled and sealed in either one of two unperforated or one macroperforated polypropylene film for 14 or 21 days at 2 °C. The atmosphere inside the macroperforated film bags remained close to the composition of air during storage. In unperforated bags, steady-state atmospheres were reached within 6 and 9 days: firm-breaker fruit (12% CO_2 and 4% O_2 in standard type polypropylene, 23% CO_2 and 2% O_2 in oriented type polypropylene); firm-mature fruit (22% CO_2 and 3% O_2 in standard polypropylene and 21% CO_2 and 2% O_2 in oriented polypropylene). After 14 days storage plus a 3-day shelf life test, woolliness and slight internal browning developed in fruit stored in macroperforated polypropylene. Ethanol and acetaldehyde accumulated to higher levels in oriented polypropylene bags for both firm-breaker and firm-mature fruit. Modified atmospheres in both unperforated bags were associated with lower weight loss, less senescence and chilling injury, absence of decay, and delayed ripening changes of the fruit after a shelf life period.

de Santana et al. (2011b) reported on peaches cv. Douradão packed in polypropylene trays and placed in low-density polyethylene (LDPE) bags (30, 50, 60, and 75 μm thickness) with active modified atmosphere (10 kPa CO_2 + 1.5 kPa O_2, balance N_2). Fruits were kept at 1 ± 1 °C and 90 ± 5% RH for 28 days. After 14, 21, and 28 days, samples were withdrawn from the modified atmosphere and kept in air at 25 ± 1 °C and 90 ± 5% RH for ripening. On the day of removal and after 4 days, peaches were evaluated for woolliness incidence and pectolytic enzymes activities. The respiratory rate and ethylene synthesis were monitored during 6 days of ripening. The results showed that LDPE film 50 μm and LDPE film 60 μm treatments had a positive effect on the inhibition of the development of woolly texture and reduced pectin methylesterase activity on the ripe fruits, keeping the good quality of the

'Douradão' peach variety during 28 days of cold storage. The treatments control, LDPE film 30 μm, and LDPE film 75 μm showed higher woolliness incidence and did not present marketable conditions after 14 days of cold storage.

In another study, Malakou and Nanos (2005) reported on peaches (cv. Royal Glory) treated in 46 °C hot water containing 200 mM NaCl for 25 min, sealed in low-thickness polyethylene bags, and stored at 0 °C for 1 and 2 weeks. Quality was evaluated initially and after each storage period plus 1 day of shelf life. Hot water treatment did not cause any fruit damage based on external observations, specific conductivity, and total phenol content evaluations, but reduced firmness loss, possibly in combination with MAP and kept the cellular membranes functioning better. Polyethylene bags were of low thickness and modified atmosphere conditions inside the bags were found to be inadequate (O_2 levels >15%, CO_2 levels <5%) to significantly affect the ripening process during cold storage, but could be harmful after 10 h at room temperature (O_2 levels <3%, CO_2 levels >13%). Mass losses were kept low in polyethylene bags. Juice soluble solids concentration, pH, and acidity were not affected by the hot water treatment before and after cold storage. Hot water combined with MAP during storage resulted in good quality fruit after 1 week duration for postharvest handling.

Heat Treatment

Peach fruit was subjected to hot water and moist hot air treatment at varying temperatures. The activities of polyphenol oxidase and polygalacturonase were monitored during storage for 0, 3, and 6 days. Polyphenol oxidase activity decreased in all treatments during storage. This decrease was greater in hot water-treated fruits than in fruits treated by hot air. Polyphenol oxidase activity decreased with the increase in treatment duration. However, the polygalacturonase activity increased in heat-treated fruits as well as controls. This increase was more in mild heat treatments as compared to severe heat. Polyphenol and pectin contents decreased during storage in both heat treatments (Bakshi and Masoodi 2010).

Spadoni et al. (2014), while investigating the influence of hot water treatment on brown rot of peach and rapid fruit response to heat stress, reported on peach fruits that were wounded, inoculated with conidia of *Monilinia laxa* and, 15 min, 3, 6, 12, 24, and 48 h after inoculation, treated by dipping in hot water at 60 °C for 20 s. It was observed that brown rot was inhibited by 85.7% when peach fruits were heat-treated 48 h after inoculation. The expression levels of cell wall genes (β-galactosidase, pectin lyase, polygalacturonase, and pectin methyl esterase) showed a general decrease in hot water-treated fruit as compared to the control, whereas phenylalanine ammonia lyase, chitinase, heat stress-related genes, and ROS scavenging genes increased their expression level in hot water-treated samples with respect to the untreated ones.

Intermittent Warming

Intermittent warming (IW) represents an effective and environmentally friendly approach to relieve chilling injury in fruit, and this process is being applied to enhance the quality and shelf life of many fruits and vegetables (Biswas et al. 2012; Liu et al. 2015; Zhou et al. 2015). This method has been shown to be effective in delaying or preventing chilling injury in peach cultivars (Zhu et al. 2010). IW involves exposing fruit to one or more periods of warm temperature during low-temperature storage. Xi et al. (2012) studied the effect of IW on yellow-fleshed peach fruit (melting type) stored at 5 °C or exposed to 20 °C for 1 day every week during storage, and reported that flesh browning was observed on the third day of shelf life at 20 °C after 21 days of storage at 5 °C, while no flesh browning was found in IW-treated fruit for up to 28 days. Significantly lower ester contents were found in peach fruit with flesh browning. The expression profiles of *PpAAT1* were similar to alcohol acyltransferase activity profiles, both of which increased during shelf life of fruit treated with IW. As precursors of esters, the levels of linoleic and linolenic acids were high in IW-treated peach fruit. Treatment with IW effectively alleviated the loss of aroma-related esters associated with flesh browning, and high levels of alcohol acyltransferase activity and *PpAAT1* expression in IW treated peach fruit contributed to the formation of the esters.

Fernández-Trujillo and Artés (1998) reported that firm-breaker and firm-mature peaches were conventionally stored for 4 weeks at 2 °C and 90–95% relative humidity or subjected to IW cycles of 1 day at 20 °C every 6 days of storage at 2 °C. Warming periods induced ripening (reduced flesh firmness, extractable juice, and titratable acidity), while during continuous storage, abnormal values of these parameters were found. After 2 weeks at 2 °C and particularly after the subsequent 3 days at 20 °C, woolliness and, to a lesser extent, vitrescence and dryness of the cortical tissue were detected. Severe levels of these disorders were found more frequently in firm-breaker than in firm-mature fruits, which mainly developed vitrescence. Three cycles of IW prevented chilling injuries but increased weight loss and senescence symptoms. Compared with conventional storage, IW increased the shelf life of firm-mature and firm-breaker peaches by 1 and 2 weeks, respectively.

In another study, Fernández-Trujillo and Artés (1997) reported that peaches were stored at the firm-breaker stage of maturity for 3 weeks at 0.5 °C. A factorial design, involving three cycles of IW for 1 day to 20 °C every 6 days of storage at 0.5 °C, and MAP were applied. During storage, respiratory activity, ethylene emission, flesh firmness, titratable acidity, total soluble solids content, and pH were monitored. The factorial design made it possible to evaluate the effects of interactions between these factors on fruit behavior. The different behaviors induced by IW and MAP account for the different patterns of ethylene emission, flesh firmness, total soluble solids, and total soluble solids/titratable acidity ratio. IW had a prolonged effect on ethylene emission, which continued to be stimulated after the first and second warmings. Intermittently warmed fruits also had the best quality attributes at the end of storage. However, IW did not improve ripening sufficiently when applied

in combination with MAP. Both IW and MAP prolonged shelf life by about 1 week which is more than the improvement by conventional cold storage.

Chemical Treatments

Chemical treatments of peach fruit, such as pretreatment with 1-methylcyclopropene, methyl jasmonate, salicylic acid, calcium chloride, oxalic acid, melatonin, and nitric oxide, are efficient in preserving quality and enhancing the shelf life.

1-Methylcyclopropene

1-Methylcyclopropene (1-MCP), an ethylene action inhibitor, prevents the ripening effects of ethylene in many climacteric fruits (Blankenship and Dole 2003). 1-MCP has been identified to bind irreversibly to ethylene receptors and prevent ethylene-dependent responses. The use of 1-MCP in postharvest science is providing both the potential to maintain fruit quality after harvest and a powerful tool to gain insight into the fundamental processes that are involved in ripening and senescence (Watkins 2006). The effect of 1-MCP on the biochemical and physiological metabolisms of peach fruit has been extensively investigated. 1-MCP can dramatically delay ripening (Hayama et al. 2008), lower ethylene production and respiratory rates (Blankenship and Dole 2003), and maintain good quality of peach fruit (Liu et al. 2005).

1-MCP was applied to early season, melting flesh peach fruit to try to extend their shelf life. 'Almog' and 'Oded', two white-fleshed peaches, were tested. The application of 1-MCP was at both 20 and 0 °C for 5, 10, and 20 h and at concentrations ranging from 0.5 to 20 μL L^{-1}. When treated at 0 °C, the fruits were stored for 5 days before removal to 20 °C for ripening. 1-MCP slowed fruit softening in a concentration- and time-dependent manner, extending the period before the fruits became oversoft. The inhibition of softening was greater when fruits were treated and held at 20 °C than if they were treated at 0 °C and held for 5 days at 0 °C before ripening at 20 °C. Five μL L^{-1} of 1-MCP for 20 h was the optimum concentration and duration of treatment for inhibition of softening. Ethylene production in peaches was not inhibited by 1-MCP at 20 °C but was inhibited after application at 0 °C. Respiration and soluble solids content were not affected by 1-MCP treatment. Titratable acidity loss was inhibited by 1-MCP in 'Almog', but the low-acid cultivar 'Oded' was not affected. When fruit from two harvests, early and late, were examined for their response to 1-MCP, softening was slower in fruit from both harvests. It appears that 1-MCP at high concentrations can extend the shelf life of rapidly softening, perishable fruits, such as early season, melting flesh peach fruit (Liguori et al. 2004).

Jin et al. (2011) investigated the effects of different concentrations (0, 0.1, 0.5, 1, and 5 μL L^{-1}) of 1-MCP on chilling injury, fruit quality, and antioxidant enzyme activities in cold-stored peach fruit and found that the treatment with 0.5 μL L^{-1} 1-MCP significantly alleviated chilling injury symptoms, including internal browning, flesh mealiness, and maintained higher fruit quality. In addition, 1-MCP inhibited the activities of polyphenol oxidase, peroxidase, maintained higher activities of antioxidant enzymes, and kept the balance of the polygalacturonase/pectin methylesterase ratio. The treatment of 1-MCP markedly inhibited the increase of electrolyte leakage and the accumulation of malondialdehyde and hydrogen peroxide. Thus, 1-MCP (0.5 μL L^{-1}) treatment is effective in preventing chilling injury and maintaining overall quality in peach fruit. The effect of 1-MCP on alleviating chilling injury may be due to its capability to enhance antioxidant enzyme activities and to reduce oxidative damage.

Liu et al. (2015) investigated the postharvest characters, phenolic compounds, and total antioxidant activities in response to 1-MCP during the ripening process of peach fruit. Peaches were treated with air (control) or 5 μL L^{-1} of 1-MCP for 24 h, followed by storage for up to 10 days at 20 °C. 1-MCP treatment best retained firmness, soluble solids, titratable acidity, and ascorbic acid. Additionally, ethylene production and respiration rate were delayed. Moreover, treatment with 1-MCP effectively postponed the onset of peak values of phenolic compounds positively identified in the peach fruit. Total antioxidant activities are an important nutritional attribute in the human diet. Our study showed that 1-MCP delayed the increase of antioxidant activity and suppressed antioxidant activities during the prolonged ripening period. These results demonstrated that 1-MCP treatment is a good practice for maintaining fruit quality, but may have complex effects on phenolic metabolism and antioxidant activity.

In another study, Liu et al. (2018) reported that peach fruit were picked at their physiologically mature stage and treated with 5 μL L^{-1} 1-MCP, IW, and a combination of 1-MCP and IW. The severity of chilling injury (CI), quality characters, and phenolic composition, as well as antioxidant properties, were measured during refrigerated storage at 2 °C plus 3 days of shelf life at 20 °C. The results showed that all applied treatments dramatically prevented the degree of flesh browning for 'Yuhualu' peach fruit. Furthermore, 1-MCP treatment was able to alleviate the negative impact of IW, and the combination of 1-MCP and IW possessed the lowest CI index and the highest fruit qualities. Additionally, treatment with 1-MCP alone or combined with IW effectively delayed and elevated the accumulation of phenolics and antioxidant capacities for peach fruit during the entire cold storage and subsequent shelf life period. The application of 1-MCP plus IW could be a favorable practice for preventing chilling injury and maintaining fruit quality for peach fruit during refrigerated storage.

Methyl Jasmonate

Jasmonates are ubiquitous non-classic plant hormones involved in plant responses to various biotic and abiotic stresses (Wasternack 2007), and also respond to fruit growth and ripening (Ziosi et al. 2008). Methyl jasmonate application inhibited or enhanced fruit ethylene production in peaches, apples, and pears at the fruit ripening stage (Fan et al. 1997; Kondo et al. 2007). Methyl jasmonate application resulted in downregulation of the ethylene biosynthetic and softening-associated genes expression during the early and late fruit development stages (Ziosi et al. 2008; Ruiz et al. 2010). Therefore, jasmonates and ethylene may affect the peach fruit ripening process. Meng et al. (2009) investigated changes in the physiology and quality of peach fruits treated by methyl jasmonate under low temperature. The results showed that the treatment of peach fruits with methyl jasmonate decreased the chilling injury index, which was possibly attributed to the higher activity of peroxidase and lower content of phenolic compounds than that without methyl jasmonate treatment. Moreover, treatments with methyl jasmonate not only enhanced the rate of soluble solids content/titratable acidity in peach fruit, but also affected the degradation of cell wall, perhaps by the regulation of cell wall-modifying enzymes and the calcium content in the cell wall of flesh.

Jin et al. (2009b) reported that peaches were harvested at the firm-mature stage and treated with various combinations of methyl jasmonate (MJ) and hot air (HA). The results showed that fruit treated with 1 μmol L^{-1} MJ vapor at 38 °C for 12 h (HMJ) and heat treatment at 38 °C for 12 h, and then treated with 1 μmol L^{-1} MJ vapor at 20 °C for 24 h (HA + MJ) had the highest quality and lowest percentage of chilling injury symptoms. HA treatment alone significantly inhibited internal browning but caused more severe flesh mealiness than other treatments. This side effect was counteracted by MJ. The percentage of extractable juice in combined treatments was higher than that in the control; however, no significant effect was found on firmness. The combined treatments resulted in higher activities of phenylalanine ammonia-lyase, superoxide dismutase, and polygalacturonase, and lower activities of polyphenol oxidase and peroxidase than the control. The combination of HA and MJ vapor treatment might be a useful technique to alleviate chilling injury and maintain peach fruit quality during cold storage. In another study, Yu et al. (2016) reported that the pretreatment of peach fruits with methyl jasmonate in combination with hot air is often effective in reducing chilling injury during cold storage. Peach fruit was treated with hot air at 37 °C for 3 days or methyl jasmonate vapor at 10 μmol L^{-1} for 24 h before storage at 5 °C. Both treatments resulted in an initial increase and then a decrease in sucrose content over the course of storage time. Soluble sugar metabolism affects the quality and chilling resistance of postharvest peach fruit. The results showed that the increase in sucrose observed during cold storage, associated with higher sucrose phosphate synthase and lower acid invertase levels, enhances the chilling tolerance observed in HA and MJ treated fruit.

Salicylic Acid

Salicylic acid (SA), a phenolic compound which is found in a wide range of plant species, has been reported to play a vital role in regulating plant growth and development (Wang et al. 2006). SA induces H_2O_2 accumulation at high temperatures while reducing H_2O_2 at lower temperatures. SA is involved in chilling tolerance through H_2O_2 metabolism mediation (Kang et al. 2003; Wang et al. 2006). SA has also been reported to reduce spoilage in peach fruit by controlling cell membrane electrolyte leakage, decreasing respiration and ethylene production, maintaining flesh firmness, and increasing antioxidant enzymes activities (Han et al. 2003). SA has been reported to regulate antioxidants and maintain dietary value during storage (Hussain et al. 2008).

Tareen et al. (2012) studied the effectiveness of SA at different concentrations (0, 0.5, 1.0, 1.5, or 2.0 mmol L^{-1}) on the postharvest life of peach fruit (cv. 'Flordaking') and reported that fruits were treated with SA immediately after harvest and stored at 0 °C for 5 weeks. Generally, all of the SA concentrations gave a higher activity of superoxide dismutase, catalase, and peroxidase during 5 weeks of storage. The 2.0 mmol SA concentrations showed the highest activity for enzymatic antioxidants. The fruit-browning enzyme polyphenol oxidase activity decreased in SA-treated fruits. SA-treated fruits exhibited higher radical scavenging activity than control fruits. The SA 2.0 mmol concentration resulted in increased fruit weight, firmness, and decreased juice pH. The higher concentration of SA (2.0 mmol) proved to be the most effective in keeping peach fruit quality intact, along with maintaining skin color and delaying fruit surface decay during storage. Conclusively, amongst all treatments, the SA 2.0 mmol application exhibited maximum antioxidants enzymatic activities, minimum weight loss, stored firmness, and decreased pH during the storage period.

In another study, Wang et al. (2006) reported on the peach fruit at commercial maturity immersed in 0, 0.35, 0.7, and 1 mM SA solution for 5 min, stored at 0 °C for 28 days, then moved to 20 °C for 3 days to simulate shelf life. The results showed that only 1 mM SA significantly maintained higher firmness and lower chilling injury, decay index, and thiobarbituric acid-reactive substance of fruit compared with the control. Studies were then conducted to determine if 1 mM SA alleviated chilling injury by influencing antioxidant systems and/or heat shock proteins of the peach fruit. The reduced-to-oxidized ascorbate ratio in 1 mM SA-treated fruit was 39, 61, and 55% higher than that in controls at the midpoint of storage, the end of storage, and after 3 days of shelf life, respectively. The reduced-to-oxidized glutathione ratio in SA-treated fruit was 68% higher than that in controls at the midpoint of storage. Ascorbate peroxidase and glutathione reductase activities in SA-treated fruit were significantly greater than those in controls during cold storage.

Calcium Chloride

Calcium is a major element of fruit, and also functions as an intracellular signal transduction molecule in many physiological processes. Calcium has an important influence on fruit quality and storability, and is used to maintain the quality of fruit during postharvest, reduce decay, and extend shelf life. Rahman et al. (2016) investigated the impact of calcium chloride ($CaCl_2$) concentrations and storage duration on the quality attributes of peach. The peach fruit were dipped in 0, 2, and 4% $CaCl_2$ solution for 10 min and transferred to cold storage at temperature 8–10 °C with a relative humidity of 80–85%. The application of $CaCl_2$ solution and storage duration significantly influenced the fruit quality of peach fruit. However, the application of $CaCl_2$ solution significantly reduced weight loss (4.98%), disease incidence (2.08%), total sugars (5.31%), TSS/acid ratio (16.27), TSS (7.38°Brix), and increased the fruit firmness (2.21 kg cm^{-2}), titratable acidity (0.47%), and ascorbic acid (5.35 mg/100 g) of peach fruits. The storage duration of peach fruit also significantly affected the fruit quality attributes during storage. The peach fruit stored for 30 days showed less fruit firmness (0.74 kg cm^{-2}) and titratable acidity (0.31%), ascorbic acid (4.45 mg/100 g), and increased weight loss (19.74%), disease incidence (16.11%), total sugars (6.07%), TSS/acid ratio (27.62), and TSS (8.54°Brix) of peach fruit. It was concluded that the peach fruit should be treated with 4% $CaCl_2$ solution to retain the quality attributes for 30 days storage.

In another study, Gupta et al. (2011) reported on peach fruits of cv. 'Earli Grande' treated with $CaCl_2$ (4 and 6%) and stored at 0–2 °C and 85–90% RH for 21 days, followed by storage at ambient conditions (28–30 °C, 65–70% RH) for 72 h. $CaCl_2$ at 6% effectively reduced spoilage, physiological loss in weight, and maintained fruit firmness, palatability rating, acidity, vitamin A content, and pectin methyl esterase activity during storage. The results revealed that peach fruits harvested at the optimum stage followed by postharvest dip in 6% $CaCl_2$ solution for 10 min can be stored for 3 weeks in cold storage (0–2 °C, 85–90% RH), with a poststorage shelf life of 3 days at ambient conditions (28–30 °C, 65–70% RH), with acceptable edible quality of fruits.

Gang et al. (2014) investigated the effects of $CaCl_2$ and salicylic acid either alone or in various combinations on the fruit quality and chilling injury of honey peaches during 20 days of cold storage and, subsequently, 3 days of ambient temperature storage. The results showed that combined treatments were better than those of each individual treatment. The combination of $CaCl_2$ and salicylic acid was the most effective treatment in alleviating chilling injury by controlling membrane permeability, inhibiting the respiration rate, and delaying polyphenol oxidase activity. The single $CaCl_2$ application was the most viable in maintaining fruit quality by keeping firmness and retarding weight loss rate during cold and subsequent ambient temperature storage. Therefore, the combined treatment of $CaCl_2$ and salicylic acid was the most effective in peach preservation, and the single $CaCl_2$ treatment can also be promoted.

Oxalic Acid

Oxalic acid (OA) is a natural organic acid present in plants. It has been reported that OA may play a role in response to environmental stress, systemic resistance, and programmed cell death in plants (Liang et al. 2009). In recent years, the treatment of OA in postharvest fruits has received much attention. It has been noted that OA increases resistance to chilling injury and maintains the postharvest quality of peach and plum fruit (Sayyari et al. 2010; Wu et al. 2011).

Razavi and Hajilou (2016) investigated the enhancement of postharvest nutritional quality and antioxidant capacity of peach fruits by preharvest oxalic acid treatment. Their results showed that the application of OA significantly enhanced antioxidant enzymes catalase, peroxidase, and superoxide dismutase activities in peach fruits during cold storage. In addition, the increases in total flavonoids, phenolics, and antioxidant activity were higher in treated than in control fruits, leading to fruit with high bioactive compounds and antioxidant potential assayed by 1,1-diphenyl-2-picrylhydrazyl and ferric-reducing antioxidant power methods. During storage, the softening rate was higher in non-treated fruit. Thus, preharvest treatments with OA could be a promising strategy to maintain fruit quality and antioxidant capacity, as well as maintain a high flesh firmness following postharvest storage and export.

In another study, Jin et al. (2014) investigated the effects of postharvest OA treatment on 'Baifeng' peach fruit stored at 0 °C and reported that the internal browning was significantly reduced by OA treatment in peaches. OA treatment markedly inhibited the increase of ion leakage and the accumulation of malondialdehyde. Meanwhile, OA significantly increased the contents of adenosine triphosphate and energy charge in peach fruit. The enzyme activities of energy metabolism, including H^+-adenosine triphosphatase, Ca^{2+}-adenosine triphosphatase, succinic dehydrogenase, and cytochrome C oxidase, were markedly enhanced by OA treatment. The ratio of unsaturated/saturated fatty acid in OA-treated fruit was significantly higher than that in control fruit. The alleviation in chilling injury by OA may be due to enhanced enzyme activities related to energy metabolism and higher levels of energy status and unsaturated/saturated fatty acid ratio.

Melatonin

Melatonin (MT) performs diverse physiological functions in plants. In addition to serving as darkness signaling and plant growth-promoting regulators, another noticeable role is its antioxidant activity associated with the protection of plants against internal and environmental oxidative stresses (Reiter et al. 2015; Tan 2015; Zhang et al. 2015). Cao et al. (2016) proved that MT ensures better prevention of chilling injury in peach fruit during low-temperature storage, and such an effect has

been attributed, in part, to MT-induced promotion of polyamine, γ-aminobutyric acid, and proline.

Gao et al. (2018) studied the effects of 0.1 mM MT on peach fruit during storage at 1 °C for 28 days and reported that MT treatment delayed the development of chilling injury (CI) in peach fruit, as illustrated by MT-treated fruit showing lower CI incidence, CI index, and firmness loss than the control fruit. MT application prevented membrane lipid peroxidation and contributed to maintaining a higher ratio of unsaturated to saturated fatty acids in peach fruit. MT treatment also stimulated the activities of glucose-6-phosphate dehydrogenase, shikimate dehydrogenase, and phenylalanine ammonia lyase, but inhibited the activities of polyphenol oxidase and peroxidase. This would help in activating the accumulation of total phenolic and endogenous salicylic acid that might have a direct function in the alleviation of CI. In another study, Gao et al. (2016) reported on two cultivars of peach fruit, 'Shahong' and 'Qinmi', that were treated with MT at 0.1 mmol L^{-1} and then stored at ambient temperature (25–28 °C) for 7 days. The results showed that MT treatment effectively slowed the process of senescence in both peach cultivars, as indicated by reduced weight loss, decay incidence, and respiration rate, as well as maintained firmness, total soluble solids, and ascorbic acid contents. MT treatment significantly enhanced the activities of superoxide dismutase, catalase, peroxidase, and ascorbate peroxidase in both cultivars, but decreased the activity of lipoxygenase, levels of superoxide anion and hydrogen peroxide, and malondialdehyde content. These results indicate that the activation of antioxidant enzymes to scavenge superoxide anion and hydrogen peroxide by MT treatment was associated with the maintenance of membrane integrity, which might be a part of the mechanism implicated in the delay of senescence in peach fruit.

Nitric Oxide

Nitric oxide (NO) is an important bioactive signaling molecule with diverse physiological functions in phylogenetically distant species (Perazzolli et al. 2006). The use of NO on postharvest fruit ripening has become a focus for many researchers because of the potential of NO to maintain fruit quality after harvest and to be a powerful tool for gaining insight on ripening processes (Manjunatha et al. 2010). An increasing number of studies indicate that the NO signal influencing fruit ripening is complicated. NO appears to play significant roles in the transit and storage of fruit commodities, and the effects of NO were linked to the inhibition of pectin depolymerization (Zhang et al. 2011), reduction of chilling injury (Singh et al. 2009), decrease in ethylene production (Zhu et al. 2006), and inhibition of phenolic metabolism (Zhu et al. 2009).

The effects of NO on ethylene biosynthesis and lipoxygenase activity in peach fruit were studied by Zhu et al. (2006). It was observed that, in peaches treated with 5 and 10 μL L^{-1} NO, 1-aminocyclopropane-1-carboxylicacid (ACC) oxidase activ-

ity, ethylene production, and lipoxygenase activity were reduced. This led to the accumulation of ACC and 1-malonylaminocyclopropane-1-carboxylic acid during storage. There was no evidence that ACC synthase activity was affected significantly by any concentration of NO. A plausible mechanism is proposed that NO is bound to ACC oxidase to form an ACC oxidase–NO complex, which is chelated by ACC to produce an ACC–ACC oxidase–NO complex, leading to a decrease in ethylene production. The increase in concentration of ACC in NO-treated peaches may result in the redirection of ethylene to 1-malonylaminocyclopropane-1-carboxylic acid production. This is a secondary effect of NO. In another study, Flores et al. (2008) reported on peaches of cv. 'Rojo del Rito' treated with 5 μL L^{-1} of NO for 4 h, at 20 °C, and then stored at the same temperature for 14 days. The ethylene production and respiratory rate of fruits treated with NO were lower than those of control fruits. Treated fruits underwent a lesser loss of firmness during storage. The degree of disintegration of cell membranes, assessed as the percentage of electrolyte leakage, was also lower in fruits treated with NO.

The effect of NO solution on pathogen infection and defense response of peach fruit against brown rot disease caused by *Monilinia fructicola* was investigated by Gu et al. (2014). The results showed that 15 μmol L^{-1} NO solution did not significantly inhibit spore germination, germ tube length, or pathogenicity of *M. fructicola*, but significantly reduced disease incidence and lesion areas in the fruit. Although 100 μmol L^{-1} NO solution effectively inhibited the spore germination, germ tube elongation, and pathogenicity of *M. fructicola*, the high concentration of NO solution caused damage to the fruit. Moreover, 15 μmol L^{-1} NO enhanced the activities of chitinase and β-1, 3-glucanase in the fruit.

Irradiation

Irradiation treatment of peach fruits after harvest have evoked much interest for the control of microbial pathogens, mold growth, and delay of ripening, thus increasing the shelf life of fruits (Kim et al. 2010). Hussain et al. (2008) investigated the effect of gamma irradiation on retaining the quality of peach fruit. The peach fruit, after harvesting at the proper maturity stage, was irradiated in the dose range of 1.0–2.0 kGy, stored under ambient (25 °C, RH 70%) and refrigerated (3 °C, RH 80%) conditions, and evaluated for different quality parameters. The anthocyanin evaluation of the fruits revealed that irradiation enhanced the color development under both storage conditions. The gamma irradiation dose of 1.2–1.4 kGy proved to be effective in maintaining higher TSS concentration, reducing weight loss, and significantly delaying the decaying of the fruit by 6 days under ambient conditions and by 20 days under refrigerated conditions.

Kim et al. (2010) investigated the effect of gamma irradiation (0.5–2 kGy) on the physicochemical properties of peaches during 6 days of storage at 20 °C and found that the gamma irradiation was able to inactivate the four pathogens *Botrytis cinerea*, *Penicillium expansum*, *Rhizopus stolonifer*, and *Monilinia fructicola*. Hardness

significantly decreased with increment of the irradiation dose level, whereas soluble solid and total polyphenol contents increased with increment of the irradiation dose. The radical scavenging activity of the irradiated peach was higher than that of the control, and its activity increased with increment of the irradiation dose level. These results suggest that gamma irradiation of peaches improved antioxidant activity but dramatically affected the hardness throughout the entire storage time.

Six varieties of peaches were irradiated in small batches at 0.29, 0.49, 0.69, and 0.90 kGy to observe the sensitivity of peaches at different dose levels. There was no dose effect on titratable acidity, Brix, and weight loss due to irradiation. Peaches irradiated at 0.69 and 0.90 kGy were darker in flesh color, more juicy, and less firm. Commercial-scale irradiation did not adversely affect shelf life but was seen to enhance ripening. Overall, consumers rated the acceptability of irradiated peaches higher than untreated peaches (McDonald et al. 2012).

Edible Coatings

Edible coatings are applied on fruits to minimize the release of respiration gases during storage, thus increasing the storage life of fruits (Ruoyi et al. 2005). Edible coating materials such as polysaccharides, proteins, and essential oils may serve as edible coatings for extending the shelf life of fruits (Rojas-Graü et al. 2008; Bosquez-Molina et al. 2010). Extending the shelf life of fresh peach using edible coatings is beneficial to preserve and maintain freshness due to its short postharvest life at room temperature and high susceptibility to pathogens causing brown rot, which is a major disease of peach fruit (Zhou et al. 2008; Sasaki et al. 2010).

Asghar et al. 2014 investigated the effects of edible gum, glycerin, and calcium lactate treatment on the postharvest quality of peach fruits stored for 32 days at 10 °C. Different concentrations of additives were prepared, e.g., peaches in treatments AS_1 and AS_2 were dipped in 1% and 2% calcium lactate solution, respectively, for 20 min and coated with xanthan gum (1%) + glycerin (2.5%), whereas peaches with treatment of AS_3 and AS_4 were dipped in 1% and 2% calcium lactate solution, respectively, for 20 min and coated with gum arabic (1%) + glycerin (2.5%), respectively. The fruits were packed in corrugated soft board cartons and stored for 1 month at ambient temperature and analyzed for various physicochemical and sensory attributes every4 days of storage. The results indicated that storage intervals and treatments had significant effects on the quality characteristics of the whole peach fruits throughout storage. Physicochemical analysis of peach fruits revealed that fruits treated with 1% and 2% calcium lactate solution and edible coating of xanthan gum (1%) + glycerin (2.5%) had little improvement on shelf life extension, while fruits treated with 1% and 2% calcium lactate solution and edible coating of gum arabic (1%) + glycerin (2.5%) maintained maximum firmness, total soluble solids, ascorbic acid content, overall acceptability, increased sugar/acid ratio, and reduced decay index and weight loss during storage.

Guillén et al. (2013) reported on harvested peaches that were coated with either *Aloe vera* and *Aloe arborescens* gels and allowed to ripen at 20 °C for 6 days. Both coatings significantly delayed ethylene production. Changes in quality parameters related to peach postharvest ripening, such as color changes, reduction of acidity, and increase in the ripening index (total soluble solids/total acidity ratio) were significantly delayed in coated fruit. In addition, both coatings significantly reduced weight loss, especially the *A. arborescens* gel. Thus, *A. arborescens* gel could be even more effective than *A. vera* gel for use as an edible coating for preserving the quality of peach fruit.

Hazrati et al. (2017) studied the effect of A*loe vera* gel coating on peach fruits during the cold storage period and reported that *Aloe vera* gel coating had significant positive effects on weight loss, color change, and sensory evaluation. The amount of weight loss, color change, total soluble solids, and titratable acidity in fruits with coating was lower than in control fruit. Also, the results showed that *A. vera* gel coating can enhance visual properties and could also lead to more favorable taste and texture.

Hussain et al. (2016) reported on carboxymethyl cellulose (CMC) coatings alone and in combination with gamma irradiation tested for maintaining the storage quality and control of postharvest gray and black mold disease of peaches. Matured green peaches were coated with CMC at a 0.5–1.0% (w/v) level and gamma irradiated at 1.2 kGy. The treated fruit including control was stored under ambient (temperature 25 °C, RH 70%) and refrigerated (temperature 3 °C, RH 80%) conditions. In fruits treated with individual treatments of 1.0% (w/v) CMC, 1.2 kGy irradiation, and combination of 1.0% (w/v) CMC and 1.2 kGy irradiation, no decay was recorded up to 6, 8, and 14 days of ambient storage. Irradiation alone at 1.2 kGy prevented the onset of disease incidence up to 4 days compared to 2 days by 1.0% (w/v) CMC coating following 30 days of refrigeration. A combination of CMC at 1.0% (w/v) and 1.2 kGy irradiation prevented disease incidence of peach up to 7 days during postrefrigerated storage at 25 °C, RH 70% following 30 days of refrigeration.

Gad et al. (2016), while investigating the development of nano-chitosan edible coating for peach fruits cv. 'Desert Red', reported on fully mature peach fruits harvested and then coated with one of the following nano-chitosan concentrations: 0.2, 0.4, and 0.8%. The fruits were stored at 0 °C and 90–95% relative humidity for 28 days and quality parameters were analyzed in weekly intervals after 7, 14, 21, and 28 days. The results of the two successive seasons 2015/16 indicated that the nano-chitosan 0.4% treatment gave the lowest fruit decay percentage and TSS/acid ratio compared with other treatments in both seasons. The highest concentration of nano-chitosan reduced fruit weight losses and maintained fruit pulp firmness. With the advancing of the cold storage period, fruit weight losses, fruit decay percentage, and TSS/acid ratio were gradually increased, while fruit pulp firmness, total soluble solids, and acidity were decreased. The best qualities of peach fruits were obtained from the 0.4% nano-chitosan treatment after 28 days of cold storage, while 0.8% nano-chitosan treatment increased the fruit decay percentage.

Hossein-Farahi et al. (2016) studied the influence of chitosan (CS) coating combined with calcium sulfate ($CaSO_4$) treatment on peach fruit and reported on fruits

coated with CS 2%, CS 3%, CS 2% + CaSO4 5%, and CS 3% + $CaSO_4$5%. Treated fruits were stored at 4 °C and 80% relative humidity for 60 days. The fruit weight loss percentage, fruit decay percentage, fruit firmness, and fruit shriveling percentage were monitored at an interval of 15 days up to 60 days. The weight loss of treated and untreated fruits increased during storage. At the end of 30 days storage, the weight loss of fruit coated with 3% chitosan was significantly reduced compared to other treatments. The highest and lowest fruit firmness was observed in peach coated with CS 3% + $CaSO_4$5% and uncoated fruits with values of 2.1 and 0.7 kg cm^{-2}, respectively. Until 45 days after harvest, peach coated with CS 3% showed the lowest fruit decay percentage and fruit shriveling percentage as compared to uncoated fruits. These results indicate that the application of CS edible coating treatment is an effective technique for keeping and maintaining organoleptic characteristics, as well as extending the postharvest life of peach fruits. The results recommend the application of 3% CS + 5% $CaSO_4$ to increase postharvest quality of peach cv. 'Alberta'.

Physiological and Microbiological Disorders

Peach fruits are susceptible to chilling injuries and attack of phytopathogenic fungi, such as *Monilinia laxa*, *Monilinia fructicola* (responsible for brown rot), and *Rhizopus stolonifer* (responsible for *Rhizopus* rot), which deteriorate fruit quality and consumer acceptance.

Physiological Disorders

Peaches perish quickly after harvest at ambient temperature due to their fast ripening and lack of anti-decomposition agents. Low-temperature storage is an effective method to slow these decay processes and maintain crop quality. However, peaches are sensitive to low temperature, which can cause physiological disorders of fruit flesh, usually called chilling injury or cold injury during cold storage, at market, or at home (Jin et al. 2009a). Chilling injury limits the storage period and shelf life of fruit, thus reducing consumer acceptance and economic value. Chilling injury develops more rapidly and severely when fruits are stored at temperatures between 2.2 and 7.6 °C than those stored at 0 °C (Crisosto et al. 1999). Chilling injury is genetically influenced and triggered by a combination of factors, such as storage temperature and storage period. It manifests itself as fruit that are dry and have a mealy or woolly texture (mealiness or woolliness), or hard-textured fruit with no juice (leatheriness), fruit with flesh or pit cavity browning (internal browning), or with flesh bleeding (internal reddening), and these symptoms are related to cell wall integrity and pectin metabolism (Lurie and Crisosto 2005). It was further investigated that peaches developing mealiness were found to be deficient in their ability

to produce ethylene, thus affecting their normal ripening process during storage (Zhou et al. 2001). The symptoms will develop and become evident immediately or over a period of several days once peaches are transferred to a warm environment (i.e., 20 °C or above) and the problem is commonly not noticed until the fruit reaches consumers (Lurie et al. 2011).

Fruk et al. (2014) reported that the metabolism of pectins participates in a number of physiological disorders during peach storage (e.g., mealiness, leatheriness, woolliness), and its biggest role is in the woolliness of these fruit, such that pectins in intercellular spaces bind the free juice into pectate gels. Disorders of pectin metabolism are caused by changes in the pectolytic enzyme activities (i.e., mainly *endo*-polygalacturonase and *exo*-polygalacturonase, pectin esterase, cellulose, lipoxygenase). Such disorders lead to an imbalance in the degradation of the pectins, which has the effect of binding the juice into pectate gels.

Several treatments to delay and limit the development of this disorder have been tested, such as controlled delayed cooling (Lurie and Crisosto 2005), modified atmosphere packaging (Steiner et al. 2006), IW (Fernández-Trujillo and Artés 1998), and pretreatment with 1-methylcyclopropene (Jin et al. 2011), melatonin (Gao et al. 2018), oxalic acid (Jin et al. 2014), and methyl jasmonate (Meng et al. 2009).

Microbiological Disorders

Brown Rot

Brown rot caused by *Monilinia laxa* Honey, *Monilinia fructicola* (winter) Honey, or *M. fructigena* (Aderhold & Ruhland) is a serious fungal disease of peaches (Mari et al. 2008). Postharvest losses due to brown rot are typically greater than preharvest losses, and routinely occur during handling, storage, and transport (Hong et al. 1997). Villarino et al. (2011) reported that the susceptibility of peaches to *M. laxa* infection was greatest when the pericarp was completely formed and the concentrations of chlorogenic and neochlorogenic acid in the pericarp are low. Melanin production by *M. laxa* is inhibited when the concentrations of chlorogenic and neochlorogenic acid in the pericarp are high and melanin is essential for penetration of the pericarp by *Monilinia* spp.

Rhizopus *Rot*

Rhizopus species are considered as among the most devastating fungi during the storage of various horticultural commodities (Salem et al. 2016). *Rhizopus* rot caused by *Rhizopus stolonifer* is one of the most common postharvest diseases of peach fruit (Northover and Zhou 2002). Among peach fruit, *Rhizopus* rot is second

only to brown rot by *Monilinia* spp. in causing serious economic losses (FAOSTAT 2015). The symptoms of *Rhizopus* rot rarely occur in orchards, as it is generally a problem of mature and fully ripe peach fruits and occurs mostly in storage. The pathogen enters the peach fruits only through injuries caused during harvesting (Parveen et al. 2016). *Rhizopus* rot appears particularly on mature fruit, when temperatures are higher than 5 °C (i.e., during processing at room temperature, shelf life, or at the consumer's home), and spreads quickly from infected to healthy fruit (Ogawa et al. 1995). The symptoms on these fruits appear as small water-soaked areas that become soft and rotten. The infected fruits are covered by white fluffy mycelium that later turn black due to sporulation. The infected tissue becomes a soft, watery rot (Parveen et al. 2016).

Control of mold disease is especially important during storage because it develops at both low as well as high temperatures (1–2 °C for gray mold; above 15 °C for black mold) and spreads quickly among fruits (Karabulut et al. 2004). The losses due to fungal decay can be ameliorated by using synthetic fungicides, which can ensure product protection. However, increased public awareness about the negative impact of these synthetic fungicide residues on human health and the environment has promoted the deregulation and restricted use of key chemical fungicides throughout the world (Cetinkaya et al. 2006). Microbial antagonists, natural compounds, or physicochemical treatments have been evaluated by different investigators (Droby et al. 2009; Nunes 2012). The use of gamma irradiation was an effective method to inactivate the four pathogens *Botrytis cinerea*, *Penicillium expansum*, *Rhizopus stolonifer* var. *stolonifer*, and *Monilinia fructicola* in peaches (Kim et al. 2010). Recent investigations reported a significant reduction of *M. laxa* incidence in fruit after water dipping at 48 °C for 12 min (Jemric et al. 2011); similarly, Spadoni et al. (2014) obtained an 85.7% reduction of brown rot in peach by dipping fruit in hot water at 60 °C for 20 s.

Conclusion

Peach is a popular summer fruit and there has been an increasing interest in their nutritional value due to their antioxidant potential. It is a highly perishable climacteric fruit and would suffer rapid ripening and deterioration after postharvest, and, thus, have a limited postharvest life at room temperature. To improve the storage life, postharvest nutritional quality, and retard metabolic changes which deteriorate peach fruits quickly at ambient temperature after harvest, low-temperature storage is widely used. However, peach fruit succumbs to chilling injury within 1–2 weeks when stored at 2–5 °C. Several treatments to delay and limit the development of these disorders have been tested, such as cold storage, controlled and modified atmosphere storage, modified atmosphere packaging, irradiation, IW, use of coatings, use of nanocomposite packaging material, use of fungicides, and different chemical treatments.

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Postharvest Biology and Technology of Apricot

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Introduction

Apricot (*Prunus armeniaca* L.) belongs to the family Rosaceae; subfamily Prunoideae and genus *Prunus*. Rosaceae is one of the largest families in angiosperms, having about 3400 species, including peaches, almonds, apples, plums, cherries, etc. They are mostly distributed throughout the northern temperate regions of the globe. Apricots thrive best in regions with cold winters and moderately high temperatures in the spring and early summer (Guclu et al. 2006; Ahmadi et al. 2008). Apricot is a drupe fruit in which a hard stone (endocarp) having a kernel/seed inside is surrounded by an outer fleshy part (exocarp and mesocarp). Its cultivation dates back to 2000 BC and China is considered to be the center of its origin (Crisosto et al. 1999). However, apricot gradually passed through the Persian Empire into the Mediterranean and was best adapted, whereas Romans were believed to have introduced apricots to Europe (Crouzet et al. 1990). Apricots are grown worldwide, with an annual global production of 3,881,204 tons in 2016. Armenia, Afghanistan, Iran, Italy, and Turkey are the largest producers of both fresh and dried apricots (FAOSTAT 2014). The color of apricots varies from orange to orange red, while some cultivars are creamy white to greenish white (Ruiz et al. 2005; Riu-Aumatell et al. 2005).

Apricot fruits are mostly destined for fresh consumption because of their short shelf life. Further, rapid softening and susceptibility to physical damage and diseases creates hurdles in their distribution. Apricots are usually harvested at the preclimacteric stage without attainment of proper flavor and taste. The stage of development at the time of harvest and changes which occur during the postharvest

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period determine the optimum fruit quality. Postharvest technology of apricots should aim at the reduction of fruit losses as well as optimization of quality throughout the postharvest chain. With advances in logistics and packaging technology, the consumption of fruits has become possible, even in distant markets.

Nutritional Value

Apricots are generally considered to be a rich source of carotenoids, ascorbic acid, polyphenols, iron, potassium, polysaccharides, fiber, and minerals (Jiménez et al. 2008; Ali et al. 2011; Hussain et al. 2011). Apricot fruits are not only important from the nutritional point of view, but they also play a very important role in maintaining optimum health. Malic acid, citric acid, and succinic acid are the major organic acids present in apricots (Bartolozzi et al. 1997). These organic acids not only contribute organoleptic properties of fruits, but they also have some other benefits. Succinic acid helps in treating diabetes, malic acid possesses some bactericidal properties, oxalic acid is used for curing wounds and ulcers, while citric acid functions as a crystal thickener in bones (Carocho et al. 2013).

Phenolic compounds and carotenoids are of immense importance due to their antioxidant potential and role in preventing many diseases. In apricots, the total phenolic composition ranges from 50 to 563 mg GAE/100 g on a fresh weight basis (Sartaj et al. 2013). Chlorogenic acid, neochlorogenic acid, (+)catechin, (−)epicatechin, and rutin are the main phenolics present in apricots (Erdogan-Orhan and Kartal 2011). About 250 g of fresh apricots or 30 g of dried apricots can meet the daily body requirements of provitamin A (Sartaj et al. 2013). Carotenoids prevent oxidative damage through scavenging the reactive oxygen species. The intake of carotenoids can decrease the risk of certain diseases like lung and prostate cancers, cardiovascular diseases, and eye problems (Johnson 2002).

Maturity Indices

The harvest date is usually determined by a change in skin color from green to yellow and also depends on the varietal character of the fruit. However, the soluble solids content (SSC) and flesh firmness are also considered as important maturity indices (Feng et al. 2013). Apricots are harvested at the preclimacteric stage and quickly marketed, as mature fruits can experience reduced shelf life and become susceptible to mechanical damage (Aubert and Chanforan 2007). Thus, apricots are picked before reaching the highest organoleptic qualities. This may lead to low rates of consumption among consumers, mainly due to the lack of flavor and internal breakdown problems (Bruhn et al. 1991). Thus, the harvesting of fruits should be planned in a manner so as to provide a balance between optimum storage potential and eating quality.

Quality Indices

Apricot fruit quality is defined by physical, biochemical, sensory, mechanical, and functional properties. Carlos and Kader (1999) provided a number of quality indices for apricots, which include fruit size, shape, and absence of defects and damage. The quality components, viz., color, SSC, and firmness of fruits, are important to the growers as well as the processors, as they affect the product appearance and consumer acceptance (Gomez et al. 2005; Luchsinger and Walsh 1998). Apricots are especially characterized for their aroma, in addition to their color, sweetness, and texture of the fruit. Practically, apricot fruit must be sweet in taste with good flavor and optimum firmness to avoid any physical damage prior to its consumption. Fruits with total soluble solids (TSS) greater than 10°Brix and acidity of about 0.7–1.0% are widely accepted among consumers. Apricots with flesh firmness of 2–3 pounds are considered ready to eat.

Apricots are traditionally harvested and graded on the basis of visual color. This may only be an approximation of fruit maturity, as other significant factors, like firmness, TSS, etc., are not taken into account. Further, this visual determination of color is subjective and likely to be influenced by environmental conditions.

New and rapid analytical methods for assessing fruit quality attributes has increased during the last decade (Chen and Sun 1991). Near-infrared spectroscopy is probably the most studied and accomplished non-destructive method applied to agricultural products. Camps and Christen (2009) reported that near-infrared spectroscopy technology could be applicable to apricot quality also and that such portable devices can help to classify fruits as per the given variability and could assist in complete follow-up of the fruits in orchards and during postharvest. Petrisor et al. (2010) confirmed the use of the acoustic impulse response technique for the determination of texture as a non-destructive measuring tool for distinguishing different stages of ripeness in apricots. Further, online packing house, screening of color, firmness, and SSC are done by using non-destructive technologies, which can aid in measuring maturity indices for fruit quality at harvest as well as after storage (Feng et al. 2013).

The electronic tongue system, which is based on potentiometric or voltammetric chemical sensors (showing sensitivity to various substances), has recently proved to be a promising tool for monitoring the effects of postharvest techniques on the apricot ripening process. The use of such type of sensors is mostly done for measuring organoleptic properties. In apricots, it was used to detect considerable differences among controlled atmosphere and 1-methylcyclopropene (1-MCP)-treated fruits (Kantor et al. 2008).

Ripening

Ripening constitutes the period from the last stages of growth to the earliest stages of senescence, making a fruit more attractive and appealing for consumption (Tucker and Grierson 1987). It comprises several changes, which are genetically well

programmed to give attractiveness and palatability to the fruit (Lelievre et al. 1997; Giovannoni 2001). This developmental stage may lead to some prominent effects, like increase in size, sugars, change in color, soft texture, development of aromatic volatiles, synthesis and degradation of pigments, and reduction in acidity of the fruit. As the ripening stage advances, the susceptibility to pathogen infection increases (Adams-Phillips et al. 2004; Giovannoni 2004).

For determining the taste of ripe fruits, the level of sugars and acids are important and the TSS/acidity ratio is used as an index of consumer acceptance. During growth and ripening stages, sugar accumulates due to carbon import from photosynthetic leaves in the form of sucrose and sorbitol in the Rosaceae family, which leads to an increase in TSS (Rhodes 1980). Moreover, apricots have sucrose as the predominant sugar, which is usually accumulated at the S_3 stage due to an increase in sucrose synthase (Morandi et al. 2008). Malic acid (the predominant acid in apricots) accumulates during the first rapid growth phase and diminishes during the maturation and ripening stages (Serrano et al. 2005). Ayour et al. (2016) reported that acidity decreases from semi-ripe, commercially ripe, and tree ripe stages, while pH, ripening index, and TSS increase. This change may be due to gluconeogenesis, which leads to the metabolic conversion of acids into sugars. Thus, ripening induces an increase in the TSS and a decrease in titratable acid content, creating the situation for the characteristic apricot fruit taste.

The composition, structure, and morphology of the fruit cell wall influence texture. Ripening leads to softening, solubilization, and depolymerization of cell wall polysaccharide and loss of sugars. These changes are mostly due to the presence and action of cell wall degrading enzymes (Brummell 2006; Goulao and Oliveira 2008). However, besides respiratory peak exhibition, ripening also involves ethylene production. The softening of apricot fruits has been reported to start even when ethylene was undetected, which shows its sensitivity to ethylene (Mencarelli et al. 2001). Cardarelli et al. (2002) reported that exogenous treatment with propylene stimulated ethylene production and also resulted in fruit softening. This confirms the role of pectin methyl esterase and glycosidases in the softening of apricot via ethylene tissue sensitivity. Electron microscopy has revealed that ripening induces changes in texture involved in the dissolution of middle lamella, which follows distortion of the primary cell wall structure, thus making the cell wall thinner.

During ripening, carotenogenesis takes place parallel to the loss of chlorophyll, in which chloroplasts are converted into chromoplasts by the degradation of chlorophyll and synthesis of carotenoids (Hortensteiner 2006). This leads to the development of yellow and orange colors. Maturity has an important effect on the evolution of pigment content. While the surface color of fruit is initially green, it starts to turn yellow with ripening due to the degradation of chlorophyll. The carotenoid content of apricots varies from 0.1 to 4 mg/100 g (Kurz et al. 2008). From the nutritional point of view also, carotenoids are a widespread group of pigments due to their provitamin A activity (Schieber and Carle 2005). β-Carotene is reported to be the main pigment in apricot clones (Ayour et al. 2016). Furthermore, good correlation between carotenoid content and color of skin and flesh was reported by Ruiz et al. (2005)

in apricot fruits. Fruits having orange flesh exhibit more carotenoid content than lighter colored fruits.

The concentration of phenolic constituents increases with the maturity of fruit and, at the fully ripened stage, it attains a maximum; however, some phenolic constituents may also decrease with the stage of maturity (Dragovic-Uzelac et al. 2007). Some studies have also shown high concentrations of phenolic compounds in unripe apricot fruits (Kalyoncu et al. 2009).

One of the important changes associated with fruit ripening is the development of flavors, which is one of the important parameters in the assessment of fruit quality. A significant number of volatile compounds is released by fruits and they vary in quantity as well as quality. The first significant study on apricot flavors was conducted by Tang and Jennings (1967, 1968), who identified nine major aromatic components. So far, more than 200 compounds have been identified in apricot, which can contribute to the aroma of fruits (Nijssen et al. 2007). Compounds like hexyl and butyl acetate are described as the main contributors, while ethyl acetate, linalool, γ-hexalactone, α-terpineol, and γ- and δ-decalactone are considered subsidiary compounds associated with apricot aroma (Aubert and Chanforan 2007; Defilippi et al. 2009). Variability in aromatic compounds depends mostly on cultivar, maturity, storage, and processing conditions. Aubert et al. (2010) reported a significant increase of lactones, esters, and terpenic compounds during the postharvest maturation stage.

Harvesting

The harvesting method adopted is crucial for determining the postharvest life, as mature fruits are more susceptible to injuries incurred during the harvesting process. As most of the postharvest pathogens are weak, they need entry points to invade fruits. Thus, mechanical injury caused during harvesting can predispose soft fruits like apricot to postharvest pathogens. Therefore, hand/manual harvesting is generally a preferred way of harvesting apricots destined for the fresh market, so as to minimize the occurrence of damage. However, it involves more time and cost. Mechanical harvesting can be used to harvest large acreages of apricot fruits rapidly but it increases the possibility of exposing fruit tissue to injuries.

Fast ripening and susceptibility to mechanical damage are two important obstacles in apricot handling and distribution. Thus, for improving the fruit quality and time of its distribution, utmost care should be taken during fruit picking and unloading in the packing line, decreasing transfers from one container to another, and the use of a suitable packing line should be encouraged (Miller 1992). Impact injury in apricot causes cellular damage, which is internal and cannot be visible until fruits are ripe. However, in some cases when impact injury is high and severe, damage can occur on peels also (De Martino et al. 2002).

Effect of Ethylene

Apricot is a climacteric fruit exhibiting a peak in ethylene production near ripening. According to the production of ethylene, apricots can be divided into three groups, i.e., low, medium, and high (Manolopoulou and Mallidis 1999). In apricots, the emission of ethylene starts relatively early before other ripeness characters are well advanced and can influence both fruit development and ripening. It can be produced from the amino acid methionine by the conversion to *S*-adenosyl-L-methionine. *S*-Adenosyl-L-methionine is transformed by the action of enzyme 1-aminocyclopropane-1-carboxylic-acid synthase to 1-aminocyclopropane-1-carboxylic-acid and then 1-aminocyclopropane-1-carboxylic-acid is oxidized to ethylene by the action of the enzyme 1-aminocyclopropane-1-carboxylic-acid oxidase (Lin et al. 2009). Although the role of ethylene as a modulator of gene expression is well documented in other species, the mechanism remains to be elucidated in apricot. Usually in climacteric fruits during ripening, a small amount of ethylene is needed to stimulate its own production for inducing autocatalysis (Lelievre et al. 1997).

The use of different ethylene scrubbers for removing ethylene from storage rooms is in commercial use, especially when ventilation cannot be used. For extending the postharvest life, delay in ripening is expected, which can be achieved by inhibiting ethylene biosynthesis or action. Various ethylene inhibitors can be used, such as aminoethoxyvinylglycine and 1-methylcyclopropene (1-MCP), which have a greater effect on the ripening of medium and high ethylene producers, rather than on low and suppressed climacteric cultivars (Defilippi et al. 2005; El-Sharkawyet al. 2008). However, reduction in the preharvest fruit drop and the rate of development of maturity attributes in several fruits including apricot have been the main focus of the use of aminoethoxyvinylglycine (Palou and Crisosto 2003; Valdéset al. 2009). 1-MCP helps in blocking ethylene receptors for extended periods of time and, hence, hinders the expression of physiological effects induced by ethylene (Watkins 2006; Valdéset al. 2009). This chemical has been reported to delay the ripening of apricots provided its time of application, cultivar, and maturity of fruit are taken into consideration (Li Dong et al. 2002). Exogenous applications of ethylene as well as propylene hasten fruit softening. In impact bruising, an increase in ethylene production takes place in tissues away from the injured site of apricot fruits (De Martino et al. 2002).

In fruits like apple, plum, and banana, the production of volatile compounds and ethylene action remains closely correlated. However, it is unclear whether the production of esters is regulated by ethylene during apricot ripening (Abdi et al. 1998). Biotechnological approaches such as using sense/antisense technology for studying the effect of ethylene on fruit development and ripening have also been used (Ayubet al. 1996; Dandekaret al. 2004). Munoz-Robredo et al. (2012) reported that ethylene, especially at the ready-to-eat phase, influences apricot fruit ripening.

Preharvest Factors Influencing Fruit Quality

Postharvest quality depends greatly upon the preharvest factors, as not much can be done to improve the fruit quality after harvest. Apricot quality is quite variable and factors like variety, geographical origin, fruit location on the tree, irrigation frequency, use of fertilizers, pest control, growth regulators, climatic conditions like temperature, hail, high wind velocity, heavy rainfall, etc. influence the overall fruit quality. Additionally, plant age, pruning, and light penetration also contribute to fruit quality and suitability, as these factors can modify the physiology, chemical composition, and morphology of fruits. Other preharvest factors that affect apricot fruit quality are crop loads, e.g., a lower crop load may result in fruits with high fresh weight, SSC, and less postharvest mealiness development. The position of fruits also influences fruit quality; for example, fruits produced in upper canopy locations are generally large in size with higher SSC than fruits in the lower canopy. Fruits from older wood age classes result in lower incidence of postharvest mealiness (Stanley et al. 2014). Consequently, the impact of these multidimensional factors results in significant fruit variability at the time of harvest, making the segregation of fruits in homogeneous batches very difficult (Grotte et al. 2006).

Tzoutzoukou and Bouranis (2008) reported that preharvest Ca foliar treatments given to apricots result in the increase in firmness and Ca content of fruit, while lowering C_2H_4 production, respiratory rates, and soluble polyuronide content. These are considered as positive changes which favor the postharvest life and marketability of apricot fruits. Preharvest Ca treatment may also influence fruit ripening and its biochemical composition (Sartaj et al. 2013).

Regulated deficit irrigation during less sensitive, non-critical phenological stages of apricot trees resulted in the saving of water resources, as well as a slight increase in TSS and firmness of fruits at the time of harvest and during its cold storage. This demonstrates it to be a viable approach for safeguarding fruit quality as well as preserving natural resources (Perez-Pastor et al. 2007).

Postharvest Handling

Apricots have a limited postharvest life at ambient temperature, as they experience rapid ripening and deterioration after harvest. The rate of deterioration is affected by intrinsic factors, as well as storage factors like temperature, relative humidity, and gaseous composition.

Precooling is a critical step in the food chain for the removal of field heat prior to transportation or storage. It helps to reduce the respiration rate of fruits, process of senescence, inhibits pathogen development, and fruit decay (Yan et al. 2017). Thus, in climacteric fruits, postharvest changes are delayed by immediate precooling and low-temperature storage. Agar et al. (2006) found that extension in the shelf life of apricots and improvement in appearance were observed when fruits were subjected

to forced-air precooling at 0 °C. Tonini and Caccioni (1991) observed that precooling using air causes early fruit flesh softening and hydrocooling may accentuate rotting in apricot fruits. However, they concluded that forced-air cooling is the most effective method of apricot precooling.

The application of low temperature is the most reliable means used for not only extending the postharvest life but also for maintaining the quality. However, it may not be enough to preserve the quality of apricots during storage and marketing (Pretel et al. 2000). Thus, complementary techniques like modified atmosphere packaging (MAP), controlled atmosphere (CA) storage, irradiation, application of edible coatings, and use of some chemical compounds are of the main interest. One of the ways for controlling bruise injury in fruits is likely to be achieved by lowering the temperature, which has an impact on cellular turgor. However, when low temperature was used on the early-harvested apricot fruits, it hindered proper aroma development (Botondi et al. 2003). Low temperature has also been shown to inhibit ethylene production as well as the appearance of bruise symptoms (De Martino et al. 2002).

Packaging

Apricots are usually picked into picking bags or plastic totes (Carlos and Kader 1999). Fruits are prepared for the market either in the field or at the packing house and involves cleaning, sorting (according to size and quality), waxing, and postharvest chemical dipping prior to packing into containers. Corrugated fiberboard and reusable plastic containers are used for packaging. Apricot fruits are packed in a tray in either single or two layers or filled by volume (about 10 kg in a box). While packing, uniformity in size should be maintained and not more than 5% count of the apricots in each container may vary by more than 6 mm when measured through the widest portion of the cross-section. They can also be arranged in polystyrene trays with plastic film, which makes it more attractive to consumers. Lately, apricots have been sold in a flow pack, which is a transparent plastic polyvinyl chloride basket wrapped in a transparent plastic having small holes for gaseous exchange. Harvested apricot fruits, when packed with low-density polyethylene ethylene and polyvinyl chloride and stored for 30 days at 0 °C and 95% RH, showed better preservation of fruit quality attributes as compared to control fruits (Kuzucu and Önder 2010).

Modified Atmosphere Packaging

Modified atmosphere technology in conjunction with low temperature can be used as a way of maintaining commercial quality of fruits like apricot. Permeability of the film to the gas, the rate of respiration of the fruits, and temperature are the main

factors which affect extension of shelf life (Beaudry 1999; Cameron et al. 1994). The atmosphere surrounding apricots can be maintained either passively or actively (Pretel et al. 2000).

Decrease in the decay development and gel breakdown was observed in apricots stored at concentrations between 10 and 15 kPa of CO_2. Two modified atmosphere packaging (MAP) treatments which produced 13–15 kPa CO_2 and either 3 or 10 kPa O_2 prevented decay development in Canino apricots for 35 days of storage and 4 days at 20.8 °C, whereas control fruits exhibited 30% decay (Kosto et al. 2002). In the same study, Canino apricots exhibited no internal browning after 2 days, while the control fruits showed internal browning up to 40%.

Polyvinyl chloride, polyethylene terephthalate, polypropylene, and polyethylene are the typical polymers used to store fruits for MAP (Mangaraj et al. 2009) and, preferably, the film must be thick (15–100 μm) for commercial and mechanical reasons (Varoquaux et al. 2002). Pretel et al. (2000) reported that the MAP approach is effective in maintaining apricot fruit quality during cold storage, while Pala et al. (1994) observed that the shelf life of fruits stored at 0 °C and packed using 50-μm low-density polyethylene film increased from 4 to 6 weeks of storage.

Innovative biodegradable packaging materials used as an alternative to regular plastic films in MAP showed that apricot fruits can be stored at 1 ± 0.5 °C and 90–95% RH for 21 days. Biodegradable packaging was the only one wherein gases were found to be stabilized and maintained until the end of storage, i.e., gases exchanged at the same rate from fruit skin as they diffused from biodegradable package and, thus, maintaining the equilibrium. However, considering other quality parameters like loss in fruit weight, fruit firmness, etc., multilayer packaging materials were considered the best for apricot fruits (Peano et al. 2014).

Controlled Atmosphere (CA) Storage

Generally, an atmosphere with 2–3% O_2 and 2–3% CO_2 is considered optimum for storing apricots. However, the exact gas composition may vary with the variety. Retention of fruit color, firmness, and extension in storage life are the major benefits of CA storage. Flesh browning and loss of flavor is also observed in fruits stored at high CO_2 concentrations (>5%) for more than 2 weeks. For most of the apricot cultivars, extension of shelf life is expected at a CO_2 level of 10–15 kPa and an O_2 level of 2–5 kPa. If apricot fruits are given prestorage treatment with 20% CO_2 for 2 days, reduction in the incidence of decay is observed during transport, as well as subsequent storage (Carlos and Kader 1999). The effect of modified atmosphere and controlled atmosphere conditions on the fruit quality of ‘Aprikoz’ apricots was compared and it was observed that fruits stored at CA were better in terms of external appearance and taste (Koyuncu et al. 2010). Furthermore, controlled atmosphere can be used as an effective method wherein ethylene production can be reduced (Gorny and Kader 1997) and can also lead to improvement in the postharvest storage quality of fruits (Guelfat-Reich and Ben-Arie 1967; Wankier et al. 1970; Claypool and Pangborn 1972).

Chemical Treatments

1-Methylcyclopropene

Apricots, when exposed to postharvest treatments of 1-methylcyclopropene (1-MCP), chlorine dioxide, calcium, and heat in sealed containers and then stored at 20 °C for 10 days, resulted in reduced respiration and malondialdehyde (MDA) content, delay in softening and postharvest decay, while increasing antioxidant capacity. 1-MCP treatment of apricots helped in the maintenance of membrane integrity, alleviation of lipid peroxidation, and enhancement of antioxidant ability. Thus, the use of 1-MCP as well as chlorine dioxide treatment helped in maintaining the quality of fruits and extending the shelf life at room temperature (Wu et al. 2015). 1-MCP was able to alleviate flesh browning in apricots even at low concentration. Canino apricots were treated with 1-MCP prior to storage and did not respond favorably, but when 1-MCP was applied as a poststorage treatment, it delayed ripening and improved fruit quality. Therefore, for successful 1-MCP application, proper selection of maturity or physiological stage is important (Dong et al. 2002).

The treatment of apricot fruits with 1 μL L^{-1} 1-MCP for 4 h at 20 °C and later storage at 0 or 20 °C was able to delay ethylene production and reduce the respiration rate. At both storage temperatures, fruits were able to maintain firmness and titratable acidity. 1-MCP-treated fruits exhibited less color changes, as well as delayed volatile production. Thus, by applying 1-MCP, inhibition of fruit ripening and improvement of poststorage quality of climacteric fruits like apricot is expected (Fan et al. 2000). Bruising of apricot fruits accelerated ripening as well as loss of firmness; however, the treatment of apricot fruits with 1-MCP helps in preventing the loss of tissue integrity and decreases in ethylene and CO_2 production, regardless of the time of application (De Martino et al. 2006). The application of 1-MCP has been shown to delay fruit softening, which is closely related to ethylene inhibition. Apricots treated with 0.75 μL L^{-1} of 1-MCP showed higher fruit firmness than fruits treated with 0.25–0.5 μL L^{-1}, confirming the reduction of softening to be dose-dependent. When apricots are harvested at S_1 and S_2 ripening stages and treated with 1-MCP, they exhibited less color changes than controls, confirming that 1-MCP retards the evolution of color in apricots. Control fruits exhibited change in color from yellow to dark orange. This effect was observed to be dose–dependent, as fruits treated with 0.5 μL L^{-1} remained more yellow than those treated with 0.3 μL L^{-1} after 21 days of cold storage (Valero and Serrano 2010).

Calcium

Calcium, a divalent cation (Ca^{2+}), has a structural function in the membranes and cell walls of fruits. It helps in maintaining membrane integrity, cell turgor, and retarding membrane catabolism. Thus, its application either preharvest or

postharvest helps in maintaining the overall fruit quality. The application of calcium mostly as calcium chloride to apricot fruits can be used for maintaining firmness, usually due to the lessening of solubilization of pectic substances (Ishaq et al. 2009).

The effect of preharvest calcium foliar application on ethylene production, respiratory rate, soluble polyuronides, and fruit firmness of 'Bebekou' apricot fruits was determined by Tzoutzoukou and Bouranis (1997). Treated fruits had significantly lower ethylene production rates than controls. After harvest, calcium-treated fruits displayed a 1-day delay in reaching the peak rate of ethylene production. The respiratory rate was significantly suppressed over a 5-day period at 21 °C out of the 7-day period examined immediately after harvesting. However, after 4 weeks of storage at 0 °C, there was no significant effect of calcium on the respiratory rate. The respiratory peak rate occurred earlier in the control fruits compared to that of the calcium-treated fruits at harvest time. Calcium-treated fruits were about 70% firmer than the untreated ones at harvest time. Fruit firmness was positively correlated to the calcium content of fruits, while the soluble polyuronide content of the fruit was negatively correlated to fruit calcium.

Pre- and postharvest applications of calcium salts on fruits have been successfully used to reduce loss of firmness and to slow down the ripening process. Antunes et al. (2003) studied the effect of postharvest calcium chloride application on the quality preservation of apricot cv. 'Beliana' and cv. 'Lindo' during storage. After harvest, apricots were dipped in 0, 1, 3, or 5% chloride solutions. Fruits treated with 3 and 5% chloride lost more weight than the other treatments in both cultivars. The cultivar 'Lindo' lost generally more weight than 'Beliana'. Firmness decreased through storage without differences between treatments in 'Beliana', but 'Lindo' fruits treated with 3 and 5% chloride lost less firmness than the other treatments. Fruits of cultivar 'Beliana' did not show differences in SSC among treatments. However, 'Lindo' fruits had lower SSC when treated with 1% chloride. Dipping apricot fruits in concentrations up to 1% $CaCl_2$ can improve storage ability.

Salicylic Acid

Salicylic acid, as a natural phenolic acid, has also shown promising effects on the inhibition of ethylene production, reducing respiration, and delaying senescence in apricot fruits (Chan et al. 2007), and, thus, enhancing the fruit quality (Tareen et al. 2012). Salicylic acid treatment retarded the ripening progress and quality loss. Its application enhanced the activity of phenylalanine ammonia-lyase (PAL), hydrophilic total antioxidant activity (H-TAA), and content of phenolics in fruit via regulating the metabolism of H_2O_2 during postharvest storage (Wang et al. 2015).

Putrescine

Polyamines are well known to improve the storability of many horticultural crops. The effect of exogenously applied putrescine on the postharvest storage life of apricot 'Tokhm-sefid' fruit at 2 °C was investigated by Zokaee Khosroshahi & Esna-Ashari (2007). The application of putrescine caused a reduction in ethylene production, as well as an increase in fruit flesh firmness. Soluble solids content and pH were reduced, and titratable acidity was increased in putrescine-treated fruits. The loss of fruit fresh weight was affected by putrescine in a concentration-dependent manner. Thus, fruit treated with higher concentrations of putrescine showed lower fresh weight loss.

During the handling and packaging of apricot fruits, several changes, such as increase in fruit firmness, delay in color changes, inhibition of ethylene production, and reduced mechanical damage, were observed after treatment with putrescine (Martínez-Romero et al. 2002).

Edible Coatings

The effectiveness of chitosan coating treatment to control weight loss and maintaining fruit quality of apricot was investigated by Ghasemnezhad et al. (2010). Fruits were coated with 0.25%, 0.5%, and 0.75% chitosan, as well as distilled water (control), and stored at 0 °C and 80 ± 2% relative humidity for 25 days. Weight loss from all treated and untreated fruits increased over storage time. The weight loss of chitosan-coated fruits was increased in comparison to untreated samples. Chitosan coatings significantly increased the content of total phenolics and antioxidant activity.

Mature apricots were coated with different concentrations of sucrose polyesters by Şümnü and Baymdirh (1995). The respiration rates, weight loss, color change, soluble solids, ascorbic acid content, titratable acidity, and pH of apricots were effectively reduced by both the 10- and 15-g L^{-1} concentrations during ambient storage. After 10 days of cold storage, both concentrations caused firmer fruit, higher pH, titratable acidity, soluble solids, and ascorbic acid.

Intermediate moisture apricots were coated with different formulations of natural corn protein 'zein' films by dipping treatment. Color change was reduced remarkably by the coating process. The control fruits presented higher values of a^*/b^* than the coated fruits. The total viable bacteria count of the control group was found to be significantly higher than the zein film-coated samples (Baysal et al. 2010).

Jiang et al. (2010) studied the effects of chitosan on the postharvest quality of apricot. The results show that, compared the control, 0.75 g L^{-1} chitosan treatment can reduce the rot ratio of fruit, alleviate fruit's ripening and softening significantly, and maintain higher total soluble solids content level. It can increase the activity of

peroxidase, superoxide dismutase, and catalase, but decrease the activity of polyphenol and the superoxide generation rate. It can also alleviate the degeneration of cell wall and chloroplast, and delay ripening and senescence in the storage of apricot fruits (Jiang et al. 2010).

Irradiation

Irradiation has become an effective means of processing and preserving food products. Irradiation has been recognized as an alternative to chemical treatments for treating agricultural products to overcome quarantine barriers in international trade. An irradiation dose of 0.3 kGy was well tolerated by apricots with less quality loss. However, with a higher irradiation dose of 0.6 kGy, loss of firmness, change in color, and accelerated internal breakdown were recorded (Arvanitoyannis 2010). Apricots, when irradiated (1 and 2 kGy), showed a significant reduction in the growth of aerobic bacteria, yeasts, and hardness during storage. However, pH, total sugars, vitamin C content, and overall acceptability of fruits was not affected (Jeong-Ok et al. 2008).

The ionization treatment significantly affected ethylene production in apricots and caused an earlier appearance of the climacteric peak and a decrease in the ethylene concentration at that peak. The texture of the apricot showed a slight tendency to softening when fruit were irradiated at 1 kGy. The other physicochemical and nutritional properties studied showed no significant changes when compared with non-irradiated fruit. Peroxidase activity, as part of the antioxidant defense system, showed a significant increase, this being greater with the higher radiation dose (Egea et al. 2004).

Sun-dried apricots were gamma irradiated in the dose range 1.0–3.0 kGy. The gamma-irradiated fruit, including control, was stored under ambient (15–25 °C, RH 70–80%) conditions. Radiation treatment at dose levels of 2.5 and 3.0 kGy proved to be significantly beneficial in the retention of higher levels of β-carotene, ascorbic acid, total sugars, and color values without impairing the taste as perceived by the sensory panel analysts. The above optimized doses, besides maintaining the higher overall acceptability of sun-dried apricots, resulted in 5 log reductions in microbial load just after irradiation and 1.0 and 1.3 log reductions in yeast and mold and bacterial count after 18 months of ambient storage (Hussain et al. 2011).

In another study, the effect of electron beam irradiation on sun-dried apricots was periodically evaluated for quality maintenance by Wei et al. (2014). The sun-dried apricots were treated with 1.0, 2.0, 3.0, 4.0, and 5.0 kGy of electron beam and subsequently stored at ambient temperature. Electron beam treatment at 1.0–3.0 kGy proved to be beneficial for retaining high levels of β-carotene, ascorbic acid, titratable acidity, total sugars, and color, without any significant effect on the sensory properties. After 10 months of storage, the maximum losses of ascorbic acid were 37.8% in control samples and 35.5% in 3.0 kGy-irradiated samples. Titratable acidity and total sugars were significantly enhanced immediately after 1.0–3.0 kGy irradiation

treatment, and both parameters showed no significant change after 10 months of storage. Samples subjected to electron beam treatment at 3.0 kGy maintained a high overall acceptability of sun-dried apricots. A decreased number of viable microorganisms to below detection limits was observed after 3.0 kGy irradiation, and, compared with the control, the logarithmic reductions after 10 months of storage were 0.98 for yeast and mold count, as well as 1.71 for bacterial count.

Postharvest Diseases

The presence of sugars, a wide range of organic acids, and high water content predisposes fruits to pathogenic infection. As fruits have low pH, they are more susceptible to fungal attacks than bacterial ones. Adopting good agricultural practices from flowering to harvest can reduce the incidence of diseases. Disease incidence also depends on the cultivar, as there are some varieties within the fruit which may be more susceptible to disease attack than others.

Brown Rot

Brown rot is caused by *Monilinia* spp. and is one of the devastating diseases of apricot (Fig. 1). Early infection may appear as blossom blight or shoot dieback, while later infections may result in fruit rot on the tree as well as during storage. The incidence of brown rot increases 2–3 weeks before harvest. Increased sugar content associated with ripening as well as decreased host defense system makes ripe fruits more susceptible to infection than immature fruits.

Disease incidence is increased due to warm, wet, or humid atmosphere, especially 2–3 weeks before harvest. These are conductive conditions for pathogen survival and infection, and can result in severe fruit loss. As most of the pathogens are weak, insect

Fig. 1 Brown rot of apricot

damage can further increase the chances of pathogen penetration by creating wounds as well as acting as vectors of fungal conidia. Initially, tan and circular brown spots appear on the fruits, which increase in size to engulf the whole fruit. Fruits eventually become shriveled black mummies, which may drop or remain attached to the tree. Disease can spread even after harvest and can result in serious postharvest losses.

Orchard sanitation is the removal of rotten/fallen fruit, and pruning will help in reducing the magnitude of infection. Harvesting should be done carefully so as to avoid the bruising of fruits. Precooling of the fruits and maintaining cool chain also helps in minimizing disease development and spread. Fruits with brown rot should be discarded and timely harvest of fruits should be encouraged. Treatments like the use of calcium chloride on fruits several weeks before harvest and surface coatings which provide physical barriers can also be used to minimize pathogen attack. Salicylic acid, as a natural phenolic acid, can be applied to enhance the local and systemic resistance in fruits against pathogens (Chan et al. 2007).

Physiological Disorders

Chilling Injury or Gel Breakdown

Fruits are usually stored at low temperatures for reducing the rate of physiological reactions, which may hasten senescence and subsequent loss of quality. Apricots and other stone fruits are, however, sensitive to low temperatures and may exhibit chilling injury after long cold storage periods. In earlier stages, it is mostly manifested as water-soaked areas, which may turn brown subsequently. Breakdown of tissue followed by sponginess and formation of a gel-like area near the stone affects consumer acceptance. This may occur due to imbalance in the activity of cell wall hydrolytic enzymes, leading to the accumulation of high molecular weight unmethylated pectins that can bind extracellular juice (Zhou et al. 2000). Apricots may appear normal even at advanced stages and it is observed that, if fruits are harvested at more advanced stages, increased chances of gel breakdown are observed. It is also found that the incidence of such disorders varies from year to year, even in the same orchard. In order to control chilling injury symptoms, intermittent warming heat shock is applied. Polyamines like putrescine, spermdine, and spermine can be used to reduce chilling injury and extend protection against lipid peroxidation by stabilizing membranes, thereby reducing changes in membrane permeability and fluid loss (Tassoni et al. 1989). When polyamines, viz., putrescine and spermdine, were used in apricot fruits, reduction in the severity of chilling injury was observed as compared to the control. Further, it was noticed that spermdine was more effective than putrescine (Saba et al. 2012). They can also help in maintaining firmness of fruits, inhibit ethylene production, and delay ripening.

Controlled or modified atmospheric storages have been seen to either increase or decrease its incidence, depending upon the concentration of gases used. Canino apricot, when held for 6 weeks in air at 5 kPa CO_2 and 3 kPa O_2, showed gel breakdown,

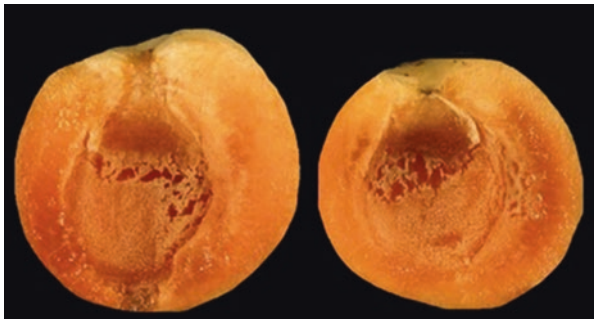

Fig. 2 Pit burn of apricot

but when CO_2 was increased to 10 or 15 kPa, it was prevented (Kosto et al. 2000). Furthermore, when apricot fruits were kept at 15 kPa CO_2, they exhibited only 7% internal browning, while at 9 kPa or less CO_2, up to 50% internal browning was exhibited. In many cultivars (Supergold, Imperial, and Peeka), gel breakdown was between 30 and 50% after storage in 15, 19, or 23 kPa CO_2 and 5 kPa O_2 (Truter and Combrink 1997).

Pit Burn

Pit burn occurs when apricot fruits are exposed to higher temperatures (>38 °C) before harvest and is manifested as flesh softening followed by browning, especially near the pit/stone area (Fig. 2). A higher nitrogen level aggravates the incidence of pit burn. However, the application of calcium can help to prevent it.

Conclusion

Apricots are an excellent source of carotenoids, ascorbic acid, polyphenols, minerals, sugars, and fiber. There is a great scope for combining pre- and postharvest strategies for the optimal quality shelf life of apricots. Preharvest conditions like cultivar, geography, irrigation, rainfall, wind velocity, fertilizers, and fruit location on the tree play a vital role in determining the overall quality of apricots. Ethylene is the prime internal factor, which causes an abrupt increase in respiration, leading to a short shelf life. Being a climacteric fruit, the harvesting of apricots is done prior to the attainment of complete maturity. The main disadvantage of this strategy is that the fruits are not of optimal quality in terms of color and flavor. Different strategies like precooling, low-temperature storage, modified atmospheric packing, controlled atmospheric packaging, chemicals, edible coatings, and irradiation have been employed for the retention of quality shelf life of apricots.

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Postharvest Biology and Technology of Apple

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Introduction

Apple (*Malus domestica*) is commercially grown in the temperate regions of the world (Arseneault and Cline 2016). It is one of the leading fruits produced in the world, with an estimated production of 89,329,179 tons (FAOSTAT 2017). The leading countries for apple production include China, India, Iran, and Japan in Asia; the United States, Mexico, and Canada in North America; France, Italy, and Russia in Europe; Argentina and Brazil in South America; and South Africa, Egypt, and Morocco in Africa. Asia has the highest apple production and the largest cultivated area in the world, followed by Europe, North America, South America, Africa, and Australia (Ferree and Warrington 2003).

There are over 5000 known cultivars of apple grown all over the world. Each country and area has its own local cultivars. However, some cultivars are familiar all over the world. For example, the most widely grown cultivars by far are 'Golden Delicious' and 'Delicious' group (Sansavini et al. 2004). Since the apple is a long-lived tree and vegetatively propagated, cultivars known for hundreds of years ago still exist.

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Apple fruit have one of the highest consumption rates in the world. Sensory qualities, such as firmness, flavor, and appearance, are important, but the nutritional characteristics are also crucial in apple consumption. They are good sources of vitamins, fibers, minerals, and antioxidants. Apple quality and the postharvest life can be influenced by several factors, including maturity indices, storage conditions, and postharvest treatments. The storage of apples in a controlled atmosphere (CA) is widely used because of the beneficial effect of CA in maintaining fruit quality and reducing the incidence of physiological disorders, both during and after storage. In addition, a number of technologies has been developed for extending the shelf life of apple fruit, each one having its own advantages.

Fruit Development

The fruit development in apple is characterized by the continuous enlargement of the receptacle and the subsequent fruit growth occurs mainly due to cell expansion. In the developed fruit, fructose, glucose, and sucrose are the principal sugars found in apple flesh and vary with stage of fruit development, cultivar, climate, and cultural practices (Aprea et al. 2017). The type and amount of nutrients, chemicals, herbicides, and pesticides also have a direct influence on the sugar content of the fruit. In apple, starch accumulates at a very early stage of its development and is hydrolyzed into sugars with the advancement of maturity. The starch disappearance is higher at the later stages of fruit development. The hemicellulose and dextrin are at higher levels at early stages of development, which gradually decline with the advancement of maturity. The titratable acidity of fruit steadily decreases as the fruit matures, but the absolute amount of acid present in the fruit increases just before harvest, when it slightly decreases (Warrington et al. 1999; Harker et al. 2002).

Fruit Maturity and Ripening

Fruit maturity at harvest is a critical factor affecting postharvest ripening and flavor development, and is, therefore, a determinant of postharvest handling of fruit. Harvest too early may result in pronounced lack of flavor development, while late-harvested fruit undergoes rapid firmness loss during storage (Mattheis et al. 1991). In contrast, harvest of unripe fruit enhances a number of desirable characteristics, such as increased ripening period and delayed decline in firmness, acidity, and green ground color relative to ripe fruit (Smith 1984). On the other hand, less mature fruit generally do not develop typical full flavor and, as a result, taste is often strongly impaired (Bangerth et al. 2012).

Ripening of apple fruit involves many physiological and biochemical changes. From an applied perspective, the most important of these are softening, the change of background or ground color from green to yellow, loss of acidity, conversion of

starch to sugars, formation of cuticular waxes, and synthesis of aromatic compounds (Knee et al. 1989). Many of these changes are at least partly desirable for human consumption, and the objective of apple industries is to harvest fruit at the appropriate maturity and apply postharvest technologies to control the rates of these changes in order to provide the consumer with an acceptable product.

Harvesting Time

Fruit flavor, one of the most important criteria in the selection of apples, is difficult to analyze since the constituents of flavor are a complex combination of acids, sugars, tannin, and aromatic substances. The basis of taste and flavor in apple is acidity and sweetness; it is the balance between these two components, irrespective of aroma, that primarily determines the acceptability of the fruit. The acidity and sweetness are inherited independently. Apples that are high in acid and low in sugar are quite unpalatable, being too acid; similarly, apples high in sugar and low in acid are too sweet and insipid. The acid in the mature fruit is almost entirely malic acid, and is measured either as a percentage of malic acid or pH of the fruit juice. The main sugars are fructose, sucrose, and glucose, conveniently measured by the refractive index as a percentage of total sugars in the fruit juice (Mahmood et al. 2012).

The harvesting time of apples for the fresh market differs from those planned for long-term storage. The harvest date within the maturation and ripening period has a profound effect on the storage quality of fruit. Generally, apples intended directly for consumption as fresh products are harvested at a later stage when color, sweetness, acidity, juiciness, and other quality attributes meet consumer preferences. As quality factors such as flavor and aroma of the fruit increase, the storage potential of the fruit decreases and, therefore, harvest decisions are a compromise between quality and storability of fruit. Before harvesting, several parameters, such as intended use and storage requirements, should be taken into consideration because these parameters are directly related to quality loss and shelf life of the fruit. However, when apples are harvested at a later stage, or the fully red stage, when acetonitrile and aroma biosynthesis are fully expressed, these fruits are no longer suitable for long-term storage, since postharvest decay and other losses will be high. For example, the optimal time for the harvesting of apple cv. Jonagold for long-term storage should be close to their preclimacteric respiration minimum, which coincides with the early onset of the climacteric ethylene production. However, the optimal harvesting time is largely dependent on the prevailing temperature and genotype–environmental interaction (Mahajan et al. 2014).

Some of the early varieties may be ready for harvest during August or early September in Asian countries like India, while in the United States, most apples are harvested later in September through October. Days after full bloom is widely used as a guideline for the maturity of apples. For example, Gala and Fuji apples have maturities at 110–120 and 170–185 days after full bloom, respectively. The objective

measurements which are used to determine the optimum harvesting dates for apples include pressure tests (for measuring firmness) using a penetrometer or texture analyzer (Harker et al. 2006).

Measuring the apple fruit maturity stage on the tree is not an easy task due to the various metabolic processes affected by the environmental conditions and production systems. However, decisions have to be made on the harvest date, which should be carried out during the optimum harvest window with respect to the desired fruit processing. During shelf life, the fruit quality maintenance is determined by the storage conditions and storage duration (Vielma et al. 2008). During the last few decades, extensive research has been carried out on the development of non-destructive sensors (Arendse et al. 2018). None of the planned approaches seem to provide all the information necessary to characterize fruit maturation and quality. Consequently, different measuring principles concerning fruit firmness, sweetness, but also volatile compounds and pigment contents of fruit have been recently used in parallel to improve the available information concerning the fruit maturity and quality (Zhang et al. 2017).

Half of the yearly yield of 'Jonagold' apples in West Europe is destined for long-term storage (Goffings and Herregods 1993). By selecting the ideal harvest time (between half of September and half of October) in combination with optimal storage conditions, climacteric ripening can be postponed for several months (Wills et al. 2001). Nevertheless, some ripening and quality loss during storage needs to be anticipated. Quality involves the level of color, sweetness, acidity, juiciness, and texture, the latter of which appears to be the main parameter in the evaluation of eating quality by consumers. When apples are harvested immature, they do not develop their full ripeness after storage, which leads to small size, poor fruit color, sour and starchy flavor, and a weak aroma. If harvest takes place when fruit are overmature, problems with fruit drop appear and apples can no longer be used for long-term storage, as this could lead to a soft mealy texture, off–flavors, and greasy skin (Little and Holmes 2000).

Nutritional Composition

Apples are one of the most consumed fruits all over the word. Apple contains biologically active compounds of various classes, such as pectins, dietary fibers, vitamins, oligosaccharides, triterpenic acids, and phenolic compounds (Vasco et al. 2009; Hyson 2011). It also contains a good source of vitamin C. The apple is one of the most important dietary sources of phenolic compounds. Fruits contain five major groups of phenolic compounds, namely, hydroxycinnamic acids, dihydrochalcones, flavanols, flavonols, and anthocyanins (Łata et al. 2009). The distribution of these compounds differs among varieties and tissue types.

Cooling

The rapid cooling of fruits after harvesting and subsequent storage at a low temperature is an effective means to increase the shelf life of fruits by reducing the respiration rate, ethylene production, disease development, and the overall decay process (Ganai et al. 2016). Fruit should be removed from exposure to radiant energy in the orchard to refrigeration, or at least shade, after harvest. However, the rapid cooling varies depending on the cultivar, maturity, and nutritional status of fruit. Early season varieties tend to soften more rapidly than those that mature in the later part of the harvest season. Rapid cooling appears to be more critical for fruit that are more likely to ripen quickly.

The main method of cooling apple fruit involves exposing fruit to air flow in refrigerated rooms. However, this method is slow and inefficient. Forced-air cooling and hydrocooling methods are also used to remove the field heat from fruit. In forced-air cooling, bins or cartons are stacked in patterns so that cooling air is forced through, rather than around, the individual container. In hydrocooling, apple temperatures are reduced by cold water flowing over the fruit surface, by either flooding, spraying, or immersion of the fruit in chilled water. The rate of internal cooling is related to the size and shape of fruit. This method is simple, economical, and effective.

Cold Storage

Apples are living tissues and are subjected to continuous postharvest processes, resulting in senescence and death (Kader 1999). Since complete inhibition of the physiological processes is not possible, decreasing the rate of them is an alternate task. Thus, the objective of storage is to prolong the life of the fruit tissues by slowing down the metabolic processes within the fruit that influence its shelf life. The metabolic processes that occur inside the fruit include, in particular, respiration intensity and internal ethylene production (Paull 1999). Both these processes are correlated with low temperature (Westwood 1993). High storage temperature or low relative humidity, or both, reduce storage potential, decrease apple quality, and enhance disorders (Robinson et al. 1975; Paull 1999).

The recommended conditions for commercial storage of apples are −0.5 to 4 °C, the desired temperature being a function of sensitivity to low-temperature-associated injuries. However, these disorders typically develop over long-term storage, and, sometimes, temperatures closer to 0 °C are used for 1–2 months storage of chilling-sensitive cultivars to maximize firmness retention. Usually, cold storage is used in combination with other technologies for the shelf life enhancement of apple.

Controlled Atmosphere Storage

The apple is the predominant horticultural commodity stored under CA conditions because of the beneficial effect of this technology in maintaining fruit quality and reducing the incidence of physiological disorders, both during and after storage. CA storage has greatly extended the marketing season of apples, which involves holding apples at approximately 0 °C in a facility whose atmosphere contains 1–3% O_2 and 1–3% CO_2 to slow down the respiration of the fruit (Thewes et al. 2017). Under CA conditions, apples can be stored for about 1 year without any appreciable loss of quality. The CA storage requires airtight refrigerated rooms that are sealed after apples are stored inside (Lavilla et al. 1999).

CA storage reduces respiration, ethylene production, and related biochemical and physiological changes. The dynamics of the metabolic changes accompanying initial periods of CA storage of 'Jonagold' apples have been studied by Bekele et al. (2016). The apples were exposed to 1 kPa O_2, 3 kPa CO_2; 3 kPa O_2, 3 kPa CO_2; 1 kPa O_2, 10 kPa CO_2; and air (20.8 kPa O_2, 0.03 kPa CO_2) was used as a control. The effect of air storage preceding CA storage was also investigated. In response to CA, metabolic changes were observed in glycolysis, tricarboxylic acid cycle, amino acids, and other metabolites linked with these pathways. In general, stress response patterns of immediate and delayed CA-stored apples were similar. Aspartate and 1-aminocyclopropane-1-carboxylic acid were positively correlated with O_2 concentration during the first 2 days and after 1 week of storage, respectively, while glucose-6-phosphate and some amino acids such as proline, alanine, and threonine were negatively correlated with O_2 concentration. Glutamate and succinate were correlated with CO_2 concentration.

Aroma compounds, quality parameters, and sensory evaluation of 'Fuji' apples were analyzed after 3, 5, and 7 months of cold storage in normal atmosphere (21% O_2 + 0.03% CO_2) and in three controlled atmosphere treatments, in which oxygen and carbon dioxide were held at proportions 1% + 1%, 1% + 2%, and 3% + 2%. During poststorage ripening, the apples were kept at 20 °C for 1, 5, and 10 days before analytical measurements were made. The highest volatile emission was obtained after 5 months of storage, at which controlled atmosphere conditions gave a lower concentration than normal cold storage. Ultra-low oxygen CA showed the highest ability to maintain the fruit firmness (Echeverría et al. 2004a).

In another study, Echeverría et al. (2004b) harvested 'Fuji' apples on two different dates, over two consecutive years, and stored under different atmosphere conditions: normal cold storage (21 kPa O_2 + 0.03 kPa CO_2), standard controlled atmosphere (3 kPa O_2 + 2 kPa CO_2), or ultra-low oxygen (1 kPa O_2 + 2 kPa CO_2). After 3, 5, or 7 months of storage plus 1 or 10 days of ripening at 20 °C, aroma volatile emission and quality parameters were measured. Generally, the highest total aroma emission was obtained after 5 months' storage and 1 day of ripening at 20 °C, regardless of atmosphere conditions, for early-harvested fruit. After 7 months' storage, the ultra-low oxygen atmosphere depressed total aroma volatile emission. The compounds contributing mostly to the characteristic aroma of 'Fuji' apples were ethyl 2-methylbutanoate, 2-methylbutyl acetate, and hexyl acetate, and their con-

centrations were higher the first day after removal from storage at 5, 3, and 7 months, respectively.

Both et al. (2014) assessed the profile of volatile compounds in 'Royal Gala' apples stored under CA, with O_2 levels ranging from 1.0 kPa to as low as 0.5 kPa during a period of 8 months (0.5 °C), followed by 7 days of shelf life at 20 °C. Straight and branched-chain esters exhibited a distinct pattern. The emission of straight-chain esters decreased under extremely low O_2 (0.5 kPa), while branched-chain esters were not significantly affected in such conditions. 2-Methyl-butyl acetate, a significant contributor to the 'Royal Gala' aroma, was higher in intermediate O_2 concentration, suggesting that lowering the O_2 levels to 0.7 kPa does not negatively affect the volatile composition of 'Royal Gala' apples as compared to the standard CA (1.0 kPa O_2). The remaining volatile compounds were not strongly affected by storing fruits under extremely low O_2.

To control internal browning injury and to reduce quality loss in 'Fuji' apples during storage, a stepwise CA method was applied. Both non-bagged and bagged apples during maturation were stored at 0 °C under 1% O_2 + 1% CO_2, 1% O_2 + 3% CO_2, or air for 10 months, and 1% O_2 + 1% CO_2 for 2 months, followed by 1% O_2 + 3% CO_2 for 8 months (stepwise CA). The concentrations of internal ethylene and carbon dioxide in apples kept for 24 h at 20 °C after storage under CA conditions were maintained at a low level, but there was no effect of stepwise CO_2 increase on internal gas concentrations. The non-bagged and bagged apples stored under stepwise CA were not significantly different from those stored under 1% O_2 + 3% CO_2 continuously for 10 months in terms of flesh firmness, titratable acidity, and yellowing index. However, the apples stored under stepwise CA were firmer, more acidic and greener than those stored under 1% O_2 + 1% CO_2 continuously for 10 months. Internal browning injury occurred in apples stored under 1% O_2 + 3% CO_2 continuously for 10 months, but it was suppressed completely by stepwise CA storage. The stepwise CA, increasing of the CO_2 level after holding at 1% CO_2 for the first 2 months of storage, was effective in maintaining the quality and controlling the internal browning injury in non-bagged and bagged 'Fuji' apples (Chung et al. 2005).

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is a technique used for prolonging the shelf life of apples (Sandhya 2010). It has become a widely used food preservation technique, as it minimally affects fresh product characteristics and it is perceived as a natural and additive-free technique by consumers (Day 1996). This preservation technique consists of substituting the air surrounding the food in the package with an atmosphere with a different composition. The atmosphere composition in the package depends mainly on the type of product, and also on the packaging materials and storage temperature. As fruit are respiring products, the interaction between the product and the packaging material is particularly important. Mainly the three gases used in MAP are CO_2, O_2, and N_2. They can be used singly or in combination, with

the aim to extend the shelf life as well as preserving the optimal sensory characteristics of the apples. Some researchers have used different packaging approaches in MAP and then evaluated the effect of packaging materials on the shelf life and quality of apples. It was found that, at 45 days of modified atmosphere, CO_2 was not detected, and ethylene production was observed only in fruits stored in low-density polyethylene film. However, there was an increase in CO_2 levels in the polypropylene treatment during the last days of evaluation. This may have been due to the low permeability of the film to CO_2 and/or the maintenance of the fruit respiration rate during that period (Krugera et al. 2010). Similarly, in another study, it was found that, after 130 days of storage at 2 °C, CO_2 concentrations inside the package doubled in 'Bravo Esmolfe' apples that were packed in polypropylene (Rocha et al. 2004).

With regard to the ethylene production, when comparing the modified atmosphere treatments, it was verified that the high-density polyethylene film showed the lowest ethylene production at 135 days of storage, possibly because of the higher concentrations of CO_2inside the package than those of the other treatments. High CO_2 concentrations are able to reduce the biosynthesis of ethylene, through both the reduction of ATP availability (De Wild et al. 1999) and the inhibitions of 1-aminocyclopropane-1-carboxylic acid synthase and 1-aminocyclopropane-1-carboxylic acid oxidase (Mathooko 2001). Thus, the high-density polyethylene film used was able to effectively delay the onset of climacteric peak. However, fruits in the control, low-density polyethylene, and polypropylene treatment groups showed an increase in ethylene production at 135 days, followed by a decrease at 225 days, according to the climacteric behavior.

MAP showed a significant effect on the firmness of apples during storage. The MAP-treated samples showed higher firmness values as compared to the controls. Apples stored under modified atmosphere lost less weight than those stored under normal atmosphere (Rocha et al. 2004). Thus, mass loss can be one of the causes of deterioration and decrease in visual quality of fresh products over time, which can lead to dehydration, wilting, loss of firmness, loss of crispness, and nutritional quality reduction, as well as senescence promotion, which reduces the enzymatic and regulatory processes of the fruit (Ben-Yehoshua and Rodov 2003). Viškelis et al. (2011) measured fruit texture and color parameters before and after 8 months of modified atmosphere conditions. Fruit firmness changed slightly when the carbon dioxide concentration in the modified atmosphere was increased. The amounts of soluble solids and sugars in fruits were stable. Fante et al. (2014) observed that storage of the Brazilian 'Eva' apple cultivar under modified atmosphere allowed the preservation of quality for up to 7 months.

Use of 1-Methylcyclopropene

It is widely recognized that 1-methylcyclopropene (1-MCP) is able to influence fruit ripening and improve poststorage quality in most climacteric fruits (Fan et al. 1999; Jung and Watkins 2014). 1-MCP blocks ethylene receptors and prevents

ethylene effects in plant tissues for extended periods (Sisler and Serek 1997). The beneficial effects of 1-MCP on respiration and ethylene production inhibition, delay of fruit ripening, and alleviation of certain ethylene-induced postharvest physiological disorders have been well recognized.

Controlling ethylene production and action is a primary goal in the postharvest management of apples. 1-MCP, an ethylene inhibitor, can delay fruit softening, yellowing, respiration, loss of titratable acidity, and, sometimes, the reduction in soluble solids, as well as the development of some physiological disorders, although volatile aroma compounds can also be inhibited (Watkins et al. 2000). The response of fruit to 1-MCP may be affected by cultivar and fruit maturity. Volatile production by apples is also inhibited by 1-MCP (Rupasinghe et al. 2000). These results are consistent with the view that volatile production is regulated by ethylene, and consumer studies on the acceptability of 1-MCP-treated fruit will be required to ensure that flavor is not unacceptably compromised.

DeEll et al. (2002) studied the efficacy of 1-MCP treatments at various temperatures and durations, to evaluate the effects of 1-MCP on 'Cortland' and 'Empire' apple quality after storage. 'Cortland' apples treated with 1-MCP at 3 °C showed improved firmness retention (>63.0 N) with at least 9 h of treatment, whereas those treated at either 13 or 23 °C showed improved firmness retention with at least 6 h of treatment. 'Empire' apples treated with 1-MCP showed improved firmness retention (>67.5 N) with only 3 h of treatment, regardless of temperature, but those treated at 3 °C for 3 h no longer had the full firmness advantage after an additional 7 days at 20 °C. Treatment with 1-MCP for 3 h at any of the temperatures significantly reduced the incidence of superficial scald in cv. 'Cortland'.

'Fuji' apple harvested 10 days before normal harvest (H_1) and at normal harvest (H_2) were untreated or treated with 1 μL L^{-1} 1-MCP and stored at 0 °C for up to 30 weeks by Lu et al. (2012). Fruits from H_1 were firmer and had higher titratable acidity but lower soluble solids concentrations than those from H_2. 1-MCP treatment delayed loss of firmness and titratable acidity in fruit from both harvests during storage. Superficial scald incidence was decreased by 1-MCP treatment, but flesh browning was unaffected. H_2 fruit had higher total phenolics, flavonoid, and glutathione content, as well as total antioxidant activity, than H_1 fruit at harvest and throughout storage. 1-MCP-treated fruit tended to have higher levels of these constituents than untreated fruit in peel, but not in flesh tissues. These results suggest that fruit harvested at the mature stage have better integral quality with 1-MCP treatment.

The efficacy of 1-MCP treatment on apple cultivars and maturity was investigated by Jung and Watkins (2014). Apple cultivars 'McIntosh', 'Cortland', and 'Empire' were categorized by internal ethylene concentrations at harvest, treated with 1 μL L^{-1}1-MCP, and the internal ethylene concentrations of individual fruit followed at 30-day intervals during air storage at 0.5 °C for 90 days. Internal ethylene concentrations at harvest ranged from <0.5 μL L^{-1} to ≥100 μL L^{-1}, 51 < 100 μL L^{-1}, and 10 < 50 μL $L^{-1}$for 'McIntosh', 'Cortland', and 'Empire', respectively. 1-MCP treatment resulted in a decrease of internal ethylene concentrations in the fruit of all cultivars by day 30 after harvest. During subsequent storage,

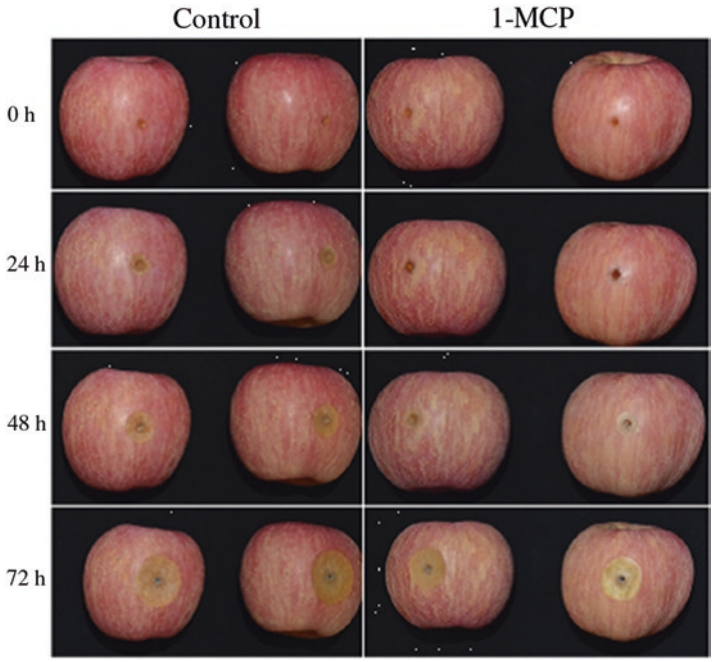

Fig. 1 Effect of 5 μL L^{-1} 1-MCP on blue mold rot caused by *P. expansum* in apple fruit. (Source: Li et al. 2017)

internal ethylene concentrations remained low in fruit, with <1 μL L^{-1} at harvest, but in 'McIntosh' and 'Cortland' increased in proportion to internal ethylene concentrations at harvest, but not in 'Empire'. The importance of initial internal ethylene concentrations in fruit on the persistence of 1-MCP inhibition of ethylene production was confirmed in a further experiment, in which internal ethylene concentrations in untreated and 1-MCP-treated 'McIntosh' and 'Empire' apples were measured for up to 194 days. 1-MCP also decreased 1-aminocyclopropene-1-carboxylic acid concentrations in the fruit.

The effect of 1-MCP on inhibiting postharvest blue mold of apple fruit caused by *Penicillium expansum* and suppressing the growth of *P. expansum* in vitro was investigated by Li et al. (2017). The treatment of 5 μL L^{-1}1-MCP significantly decreased disease severity of apple fruit caused by *P. expansum* and suppressed the mycelial growth and spore germination of *P. expansum*(Fig. 1). After treatment with 1-MCP, lower integrity of plasma membrane in the spores of *P. expansum* was detected, higher levels of reactive oxygen species in the spores and malondialdehyde in the mycelium was observed, indicating that 1-MCP treatment enhanced oxidative damage to *P. expansum* and destroyed the integrity of plasma membrane of spores.

The effects of calcium (Ca) in combination with 0.6 and 1.0 μL L^{-1}1-MCP on flesh firmness and aroma volatiles has been investigated on 'Fuji' apples stored at

room temperature by Lu et al. (2018). The results from electronic nose detection and texture evaluation showed that 1-MCP (0.6 L^{-1}) presented an interactive effect with Ca application on promoting volatile emission and reducing softening. The amount of branched and straight esters and total aroma volatiles, as well as related enzymes, including aromatase-related acyltransferase, alcohol dehydrogenase, and pyruvate decarboxylase, were significantly higher in fruit treated with 1-MCP 0.6 + Ca than 1-MCP 1.0 after 50 and 100 days' storage. There was no significant difference between the two treatments 1-MCP 0.6 + Ca and 1-MCP 1.0 in maintaining fruit firmness. Fruit treated with 1-MCP 0.6 + Ca had higher aroma quality than 1-MCP 1.0 according to sensory evaluation, but showed no significant difference in terms of texture quality. The 1-MCP of reduced concentration combined with calcium treatment had a synergetic effect on the aroma formation and softening inhibition of apple fruit, resulting in advanced sensory quality.

In another study, Gago et al. (2016) investigated the effect of calcium chloride and 1-MCP alone or combined on the incidence and development of physiological disorders and the delay of ripening of apples during storage (at 0.5 °C in air) and subsequent shelf life at room temperature ≈22 °C. 'Golden Delicious' apples were harvested in ten orchards and treated with calcium chloride (1.5%, w/v), 1-MCP (625 nL L^{-1}), calcium chloride plus 1-MCP, and without any treatment (control). The 1-MCP treatment was effective in preventing superficial scald, slowing softening, increasing soluble solids content, and reducing electrolyte leakage and color changes associated with ripening, during storage, and shelf life. However, this treatment also enhanced the development of bitter pit, especially the moderate and severe symptoms in some orchards, which may be attributable to orchard cultivation techniques. Calcium chloride alone and calcium chloride plus 1-MCP reduced bitter pit intensity by reducing moderate and severe incidence, maintained higher lightness, and had firmer fruit than the control. Postharvest dips of 'Golden Delicious' apples in $CaCl_2$ before 1-MCP application (CA + MCP) may be a good solution to prevent scald and reducing the bitter pit, which is enhanced by 1-MCP alone.

Tomic et al. (2016) compared the effects of 1-MCP and diphenylamine postharvest prestorage treatments on changes in the sensory properties of 'Granny Smith' apples during cold storage, along with subsequent keeping of fruit at room temperature. 1-MCP samples showed relatively low rates of juiciness, cohesiveness, hardness, crunchiness, greenness, and sourness reduction during the observed period of storage as compared to control and diphenylamine samples. The highest level of freshness loss during the storage period was observed in control samples, which undergo changes in quality after 9 months of storage at such a level that the fruit were decayed and not suitable for consumption. The most resistant to scald forming were 1-MCP-treated apples. No scald was found after 9 months of cold storage. The treatment of 'Granny Smith' apples with 1-MCP extended the storage time in standard normal atmosphere storage for at least 3 months without significantly losing freshness, even 2 weeks after removal from cold storage, and is more effective in preserving sensory attributes related to apple freshness when compared with the diphenylamine treatment.

The use of 1-MCP in combination with CA can further improve the storability of fruits. It must be kept in mind that only good quality apples with long storage potential should be cold stored in controlled atmospheres. Immature or overripe apples should not be held in this manner (Bai et al. 2005). DeEll et al. (2016) investigated the effects of multiple 1-MCP treatments on fruit quality and disorder development in apples, with a second 1-MCP treatment applied after several months of CA storage. 'McIntosh', 'Empire', and 'Northern Spy' apples were harvested from commercial orchards and cooled overnight to 3 °C. 1-MCP (1 μL L^{-1}) was applied 2 days after harvest and then again to half of the fruit after 4 months of CA storage. 'Northern Spy' apples also received a single 1-MCP treatment after 4 months of CA storage. Similarly, fruit from all cultivars were also not treated with 1-MCP. 'McIntosh' and 'Empire' were held at 3 °C and 'Northern Spy' at 0 °C for 9 months in CA storage (2.5 kPa O_2 + 2 kPa CO_2 for 'Empire', 2.5 kPa CO_2 for 'Northern Spy', and 2.5 up to 4.5 kPa CO_2 for 'McIntosh'). Overall, 1-MCP reduced internal ethylene production and improved firmness and acidity retention in all apple cultivars. The addition of a second 1-MCP treatment after 4 months of CA storage further improved firmness retention in 'McIntosh' and late-harvested 'Empire' apples after 7 days at room temperature. 'Northern Spy' apples treated with 1-MCP had lower incidence of external CO_2 injury, regardless of 1-MCP treatment timing. Multiple 1-MCP treatments had varying effects on the incidence of core browning; late-harvested 'McIntosh' treated twice with 1-MCP exhibited the highest incidence of core browning, while late-harvested 'Empire' treated twice had less core browning than those that were not treated. 'Northern Spy' treated only at harvest time had more core browning compared to those treated only or also after 4 months of CA storage and non-treated fruit. 1-MCP treatment had no significant effect on the incidence of internal browning in 'McIntosh' or 'Empire' apples.

The quality of 'McIntosh' and 'Empire' apples after treatment with 1-MCP and delayed CA storage has been investigated by Watkins and Nock (2012). 1-MCP suppressed the internal ethylene concentrations of the fruit during the14-day period before CA conditions were applied, but the extent of suppression was lower in fruit with high ethylene concentrations at harvest. Untreated fruit of both 'McIntosh' and 'Empire' exposed to CA storage after 2 days maintained firmness similar to 1-MCP-treated fruit, but only for 1 day of shelf life. 1-MCP treatment resulted in firm fruit after delayed CA up to 14 days, but the most consistent effects were found in 'Empire', which has lower internal ethylene concentrations than 'McIntosh'. Orchard block differences in internal ethylene concentration affected the persistence of 1-MCP effects on firmness. The effects of 1-MCP treatment on storage disorders were inconsistent, although slight increases in the risk of external carbon dioxide injury were detected. Rapid treatment of fruit with 1-MCP after harvest can afford storage operators more freedom to delay CA storage application, but attention to cultivar, fruit maturity, and susceptibility of fruit to storage disorders must be considered.

The effect of 1-MCP on ripening and concentrations of total phenolics, flavonoids, anthocyanins, and total antioxidant activity of 'Empire' apples was studied by Fawbush et al. (2009). Fruit were stored in air for up to 5 months, and in CA of 2 and 3 kPa O_2 (2 kPa CO_2) at 0.5 and 2.2 °C for 4.5 and 9 months. Ripening was delayed by 1-MCP treatment in both air and CA storage, as indicated by lower

internal ethylene concentrations and slower softening than in untreated fruit. Total phenolic, flavonoid, and anthocyanin concentrations, as well as antioxidant activity, were relatively stable during air and CA storage. In air-stored fruit, the total phenolic concentrations were higher in the peel of 1-MCP-treated fruit than in the control fruit, but slightly lower in the flesh of 1-MCP-treated fruit. In CA-stored fruit, interactions between O_2 partial pressures, temperature, and storage duration were detected, but, overall, few consistent trends were observed. However, flavonoid concentrations were higher in the flesh of 1-MCP-treated than untreated fruit kept in 2 kPa O_2 while anthocyanin concentrations, only measured in the peel, were not affected by 1-MCP treatment. Ascorbic acid concentrations declined in both peel and flesh tissues of untreated and 1-MCP-treated fruit stored in air, while changes of ascorbic acid concentrations in CA-stored fruit were inconsistent.

It is recognized that 1-MCP is able to influence fruit ripening, reduce superficial scald, and improve poststorage quality in apples. However, 1-MCP may also increase disorders such as bitter pit and diffuse skin browning. Gago et al. (2015) investigated the effect of 1-MCP (625 nL L^{-1}) and three different maturity stages (early, middle, and late harvest date) on the incidence and development of physiological disorders and ripening delay during storage at 0.5 °C and subsequent shelf life at room temperature ~22 °C, in 'Golden Delicious' apples. 1-MCP treatment of 'Golden Delicious' was effective for slowing softening and reducing electrolyte leakage and color changes associated with ripening (lightness and hue parameters). 1-MCP inhibited superficial scald and significantly reduced rot; however, this treatment enhanced the development of bitter pit in some orchards. The harvest date did not influence scald, bitter pit, and firmness, but decreased weight loss, total phenols, soluble solid content, and antioxidant activity from the second to third harvest. The application of 1-MCP, 3 days after cold storage, to 'Golden Delicious' apples, reduced ripening and superficial scald, did not induce diffuse skin browning, but increased bitter pit incidence.

Coatings

The postharvest quality of perishable horticultural produce likes apples changes rapidly due to accelerated rates of transpiration, respiration, and ripening. In order to overcome these changes, there is a need to develop alternative strategies, such as the use of bioactive edible films and coatings. The concept of using edible films or coatings to extend the shelf life of fresh fruits has been receiving considerable attention in recent years. The use of coatings and films formulated with bioactive compounds in order to convey new functionalities or extending the shelf life of apples offer a multitude of benefits to both consumers and the food industry.

Dávila-Aviña et al. (2014) incorporated olive leaf extracts in chitosan for the development of bioactive edible films and coatings for various apple cultivars and reported that weight loss and decay area significantly increased in uncoated films, and the reverse was the case for coated samples. The addition of olive leaf extract to

chitosan coating films meaningfully reduced the gradual decline in total phenolics, flavonoids, and antioxidants.

Apples cv. 'Bravo de Esmolfe' was coated with a polysaccharide-based or a protein-based coating. Alginate and gelatine coatings at different concentrations plasticized with glycerol and carboxymethyl cellulose plus sucroesters coatings plasticized with mono/diglycerides were tested. The 2% alginate and 5% gelatine coatings significantly reduced weight loss, thus maintaining fruit firmness and, thereby, preserving fruit freshness. The effects of those coatings also include the improvement of appearance and imparted an attractive natural looking gloss to the fruit (Moldao-Martins et al. 2003).

The effect of nanochitosan-based coating on the quality and storage life of apple cv. 'Golab Kohanz' was studied by Gardesh et al. (2016). The results showed that coating significantly reduced weight loss, respiration rate, ethylene production, and peroxidase activity of the samples compared with the control. Coating had a significant effect on polyphenol oxidase activity, slowed down the softening process, and improved the flesh color after the climacteric peak. Nanochitosan coating with 0.5% chitosan concentration significantly extended the quality and prevented the weight loss of the fruits, over the entire storage period. Edible coating formulated with candelilla wax and fermented extract of tarbush was applied for immersion to evaluate its effects on the shelf life and quality of 'Golden Delicious' apples in marketing conditions stored at room temperature. Edible coatings were able to reduce significantly the change in appearance, weight loss, water activity, and firmness of the apples. The results of the sensory evaluation demonstrated that edible coating with fermented extract of tarbush did not alter the appearance and taste of apples (De León-Zapata et al. 2015).

Apple fruits were sprayed with six different coating formulas, including chitosan–water wax coating, in addition to the uncoated fruits. The bioactive substances drastically changed in uncoated rather than coated fruits. Conversely, weight loss and decay area significantly increased in uncoated fruits. Amazingly, the addition of olive leaf extract to chitosan coating films meaningfully reduced the gradual decline in total phenolics, flavonoids, and antioxidants. Olive pomace extract recorded the lowest influence on anthocyanins during storage at 4 ± 1 °C for 35 days. Also, both olive leaf and pomace extracts enhanced the coating distribution, due to no pores being observed in the fruits' surfaces. Decidedly, the incorporation of olive leaf extracts with a proportion of 2% into chitosan coating solution was the best formula compared with the others. Thus, olive waste extracts, incorporated into chitosan fruit coatings, relatively improve the nutritional quality of apple fruits during postharvest (Khalifa et al. 2017).

The shellac and several coating formulations, including candelilla wax and shellac carnauba, were applied on different cultivars of apples, viz., 'Delicious', 'Fuji', 'Braeburn', and 'Granny Smith'. The shellac coating resulted in maximum fruit gloss, lowest internal O_2, highest CO_2, and least loss of flesh firmness for all of the varieties. The 'Granny Smith' cultivar with shellac had low internal O_2 (<2 kPa) with both freshly harvested and 5-month-stored apples, and the freshly harvested 'Braeburn' had high internal CO_2 (25 kPa). This excessive modification of internal gas induced an abrupt rise of the respiratory quotient, prodigious accumulation of

ethanol in both ‘Braeburn’ and ‘Granny Smith’, and flesh browning at the blossom end of ‘Braeburn’. In addition, the shellac coating gave an unusual accumulation of ethanol in freshly harvested and 5-month-stored ‘Fuji’. Candelilla and carnauba–shellac coatings maintained more optimal internal O_2 and CO_2 and better quality for ‘Fuji’, ‘Braeburn’, and ‘Granny Smith’ apples, although even these coatings may present too much of a gas barrier for ‘Granny Smith’. In general, the gas permeabilities of the coatings were useful as an indicator of differences in coating barrier properties, but did not account for differences in pore blockage (Bai et al. 2003).

Physiological Disorders

Bitter Pit

Bitter pit occurs mainly during the period of cold storage and is characterized by brown corky spots just under the skin, which dehydrate with time and form depressions in the skin of fruit (de Freitas et al. 2015). The susceptibility of fruit to bitter pit has three components: genetic, climatic, and orchard management. Even within susceptible cultivars such as ‘Golden Delicious’, seasonal differences are common, i.e., hot dry summers are associated with higher disorder incidence than cooler summers. Bitter pit is a physiological disorder of apples that has been related to calcium deficiency in the fruit (Saure 1996). Preharvest calcium sprays are commonly applied to reduce bitter pit development (Ferguson and Watkins 1989). Rapid cooling and CA storage may also reduce its development during storage.

Senescent Breakdown

Senescent breakdown incidence is related to the harvesting of overmature fruit or fruit with low calcium concentration (Prange et al. 2011). It can be exacerbated by storing fruit at higher than optimal temperatures. Its incidence has also been aggravated by low calcium levels in the fruit or prolonged storage (Saks et al. 1990). This disorder affects the skin and manifests as diffuse browning and roughening of the skin. The incidence of senescent breakdown can be reduced by the application of calcium chloride, harvesting fruit at a less mature stage, rapid cooling, and reducing the duration of storage.

Superficial Scald

Superficial scald is one of the most common physiological disorders causing brown or black patches on fruit skin that appear during or after storage on certain cultivars of apples (Lurie and Watkins 2012). Scald reduces significantly the market quality

of fruit and causes economic losses for the tree fruit industry. Various factors, including cultivar, climate, and harvest date, affect susceptibility of fruit to the disorder (Emongor et al. 1994). Du et al. (2017) reported that the antioxidant and redox system, phenyl propanoid metabolism, ethylene biosynthesis, allergens, sulfur amino acids containing proteins, and programmed cell death have a direct link to the scald development. Diphenylamine is usually applied with a fungicide to reduce decay incidence, and calcium salts may also be included at the same time to reduce bitter pit or senescent breakdown. The low oxygen and low ethylene CA storage also reduce the scald incidence.

Chilling Injury

Chilling injury is among the most common disorders recognized by the apple industry. It is physiological damage to fruit cell membranes that may occur due to adverse environmental conditions during the growing season, transportation, distribution, or storage. The membrane damage leads to secondary effects, such as ethylene production, increase in respiration, and an alteration of the cellular structure, causing the fruits to be more susceptible to diseases. This injury first appears as a slight browning discoloration of the flesh, sometimes accompanied by core browning. The chilling injury disorder of apples can progress quickly to make the fruit unmarketable (Watkins and Jackie Nock 2004). It is difficult to detect and diagnose chilling injuries at an early stage, as the injured produce often looks sound, as long as it remains at low temperatures. Chilling injury symptoms only become apparent as the temperature rises (ElMasrya et al. 2009). Damage in fruit cell membranes due to chilling injury affect normal firmness and lead the fruit to gain a spongy texture.

Pathological Disorders

The main postharvest diseases of apples which develop during storage are blue mold caused by *Penicillium* species and gray mold caused by *Botrytis cinerea*. These species enter fruit primarily through cuts, stem punctures, or bruises. Blue mold and gray mold are usually controlled during long-term storage by the postharvest application of benzimidazole fungicide, thiabendazole, or diphenylamine.

Conclusion

The shelf life of apples is affected by a number of factors, such as harvesting operations, storage conditions, etc. They have a relatively long storage life compared with other fruits crops. However, the main problem of apple storage is the fruit firmness,

which is one of the most important determinants of fruit quality and consumer acceptability. As apple crops are harvested in a short period of time, storage techniques are developed to maintain fruit quality and increase the period of supply to the consumer market. In addition other techniques, such as modified atmosphere packaging, use of 1-MCP, coatings, etc., have been exploited to increase the shelf life and postharvest quality of apple.

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Postharvest Biology and Technology of Pear

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Introduction

Pear (*Pyrus communis* L.) is popular with consumers for its unique fragrance, subtle aroma, sweetness, and crispness. It is a typical fruit of temperate climates, with delicate pleasant taste, and has a wide acceptance throughout the world. It has high nutritional value with reasonable amounts of vitamins A, B_1, B_2, B_3, and C, and minerals like sodium, potassium, phosphorus, calcium, magnesium, and iron. It has a lot of fiber, giving excellent results in the treatment of constipation and intestine inflammation.

Commercially, it is divided into two major groups: European and Asian pears. European pears have elongated shape with full-bodied texture, while Asian pears have a rounded body with sandy texture (Layne and Quamme 1975; Shen 1980; Anon 2010). Pear is used mostly for fresh consumption or for the production of jams (Jackson 2003). The annual production of pear fruit is 27,345,930 tons, with the highest being in China, at 19,288,063 tons (FAOSTAT 2017). It is the ninth most important cultivated fruit in the world. China is the world's largest producer (Asian pear) and the United States is the second largest producer, being the first producer of the European pear type also (Anon 2010).

The fresh pear fruits are commonly used for table purposes, as it has good eating quality with few stone cells. It matures in middle and late August, and is typically harvested at a minimum soluble solids concentration of 10–12 °Brix. Pears are harvested during a relatively narrow range of fruit maturity and require prompt cooling to remove field heat (Hansen and Mellenthin 1979). Pears have a short shelf life of 7–10 days at room temperature (25–30 °C) without packaging and are susceptible to decay, mechanical damage, and moisture and nutritional losses during storage.

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In the North Eastern Hill Region of India, during harvest season, growers do not obtain remunerative prices at local markets due to glut and farmers are forced to sell their produce at throwaway prices.

Pears are harvested in the month of August, during which the temperature is comparatively high and, therefore, they cannot be transported and stored for longer periods. Moreover, the rapid ripening process is also responsible for the short shelf life of pear fruit and it represents a serious constraint for efficient handling and transportation (Zerbini 2002). This chapter will extend and complement the literature related to the postharvest biology and technology of pear fruit for enhancing its postharvest handling and shelf life.

Role of Ethylene in Ripening

The process of ripening is initiated by the plant hormone ethylene. On the basis of ethylene production and response to externally applied ethylene, fruits can be classified into climacteric and non-climacteric. Climacteric fruits, such as apples and pears, display a burst in ethylene production and respiration during ripening. However, non-climacteric fruits, such as cherries and strawberries, do not require ethylene during the ripening process. In climacteric fruits, ethylene evolution can reach 30–500 ppm/(kg h) (parts per million, microliters per liter), whereas in non-climacteric fruits, the ethylene levels usually range from 0.1 to 0.5 ppm/(kg h) during ripening (Paliyath and Murr 2008).

The rate of ethylene biosynthesis is also influenced by several external factors that mainly include storage temperature and the levels of O_2 and CO_2 during postharvest storage. It has been found that, in some temperate fruits such as pears, ethylene synthesis can be induced by low temperature. Delayed fruit ripening and reduced fruit drop was noted in aminoethoxyvinylglycine-treated apples and pears (Rath et al. 2006).

The regulation of ethylene biosynthesis is a critical factor in the preservation of shelf life and quality in fruits. Controlled atmosphere storage under low oxygen reduces ethylene production. Ethylene scrubbing is also a common practice in storage facilities. Biotechnological approaches to reduce ethylene production by tissue through the regulation of the activities of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase have provided additional methods for the preservation of quality in fruits. Some examples include the inhibition of ACC synthase and ACC oxidase gene expression through the introduction of their respective antisense cDNAs, which caused delayed ripening and resulted in better preservation of the quality of apple fruits (Hrazdina et al. 2000). ACC synthase is the rate-limiting enzyme of the ethylene biosynthetic pathway and requires pyridoxal-5-phosphate as a cofactor. ACC synthase is inhibited by pyridoxal phosphate inhibitors such as aminoethoxyvinylglycine and aminooxyacetic acid. Field application of aminoethoxyvinylglycine as a growth regulator (retain, valent chemicals) is a practical method of delaying the ripening in fruits such as apples, peaches, and pears.

Also, controlled atmosphere storage at very low oxygen levels (1–3%) is a common practice in commercial operations for the long-term storage of fruits such as apples to reduce the production of ethylene, since oxygen is required for the conversion of ACC to ethylene (Dussi et al. 2002).

Storage and Shelf Life

Several factors influence the postharvest losses in fruits and vegetables, which include losses due to physical, physiological, and mechanical attributes, unhygienic conditions, lack of proper storage conditions, refrigerated facilities, and diseases and pests, etc. During harvesting to handling for storage till marketing, several wound pathogens are known to infect the produce that destroy the keeping quality as well as quantity and, ultimately, lead to economic losses. Postharvest decay of fruits occurs either between flowering and fruit maturity or during harvesting and subsequent handling and storage. Wound pathogens mainly cause postharvest infections that occur through surface wounds inflicted during harvest and handling. Even fruit that appears healthy when harvested may cause significant losses during storage due to the quiescent and latent infections in the field, and these latent infections become a major factor for decay during transportation or storage (Sharma et al. 2009).

Cold Storage

Cold storage has been recommended for the shelf life extension of pear fruit. Thus, the objective of storage is to prolong the shelf life by slowing down the metabolic processes within the fruit that influence its shelf life. Pasquariello et al. (2013) investigated the physiological changes in six summer pear cultivars, including Carmen, Coscia, Etrusca, Precoce di Fiorano, Tosca, and Turandot, during cold storage. The maximum weight loss was recorded in Precoce di Fiorano, ranging from 3.6 to 6.0% after 8 and 12 weeks of cold storage, respectively. Additionally, the titratable acidity was affected by the cold storage, and some cultivar-specific changes were observed. Carmen and Tosca showed a similar percentage decrease in the titratable acidity values compared to all the other tested cultivars. Precoce di Fiorano showed rapid fruit decay as the cold storage period progressed; this cultivar preserved its physicochemical and sensory traits only for a short cold storage period (i.e., 4 weeks), whereas Etrusca, Carmen, and Turandot can be refrigerated for 8 weeks with acceptable changes in their organoleptic characteristics. Coscia and Tosca showed the longest storability (i.e., 16 weeks).

The effect of canopy position and cold storage duration (9, 12, and 16 weeks) on mealiness incidence and sensory attributes of ‘Forelle’ pears and the effect thereof on consumer preference for eating quality and appearance of the pears was studied

by Cronje et al. (2015). In 2011, inner canopy pears that were cold-stored for 12 and 16 weeks and ripened were preferred for eating quality. Mealiness was generally low in inner canopy pears and significantly lower than in outer canopy pears. Mealiness was low for both canopy positions after 16 weeks cold storage plus ripening. While the preference for inner canopy pears after 12 weeks storage may relate to the lower incidence of mealiness, the reasons for the preference after 16 weeks cold storage are uncertain. In 2012, the incidence of mealiness in outer canopy pears was double that of inner canopy pears, which may explain the general consumer preference for inner canopy pears. Mealiness levels decreased from 9 and 12 weeks cold storage to 16 weeks cold storage in 2012. This study, therefore, supports the mandatory 12 weeks cold storage period at −0.5 °C for 'Forelle' pears to ensure optimum eating quality.

Wang et al. (2017a) noticed that the low-temperature conditioning alleviates peel browning by modulating the energy and lipid metabolisms of 'Nanguo' pears during shelf life after cold storage. Fruit were initially stored at 10 °C and then cooled over a 20-day period, which delayed the incidence of peel browning of pears. Low-temperature conditioning treated fruit showed a decrease in the content of malondialdehyde and relative leakage rate of the peel. The ATP content and energy charge were higher in low-temperature conditioning treated pears. The gene expression levels of transcripts for NADH dehydrogenase, ATP synthase, and vacuolar proton-inorganic pyrophosphatase, which were involved in oxidative phosphorylation, were all upregulated by low-temperature conditioning treatment. Gene expression levels of phospholipase D involved in the glycerophospholipid metabolism were lower in low-temperature conditioning treated fruit during shelf life. These results indicate that low-temperature conditioning treatment can effectively alleviate the peel browning of pear.

The effects of low-temperature conditioning on fruit quality and peel browning spots development in 'Huangguan' pears during cold storage, especially with respect to the molecular basis of peel browning spots development, was investigated by Li et al. (2017). Fruit were directly stored at 0 °C (control) and conditioned at 10 °C for 3 days (low-temperature conditioning), respectively. Afterwards, all fruit were stored at 0 °C. Fruit firmness was unaffected by the low-temperature conditioning treatment. However, the soluble solids content was higher in the low-temperature conditioning treated fruit than in the control fruit on days 30 and 60. Compared with the control, low-temperature conditioning treatment effectively inhibited the development of peel browning spots, reduced the activities of lipoxygenase (LOX) and polyphenol oxidase (PPO), reduced malondialdehyde (MDA) content in peel tissue, invoked decline in the phenolic content, and it showed higher proline content before the appearance of peel browning spots. In addition, low-temperature conditioning treatment decreased the expression levels of LOX1, PPO1, and PPO5 genes, while it upregulated the expression of the PPO4 gene in peel tissue. These results indicate that the alleviation effect of low-temperature conditioning on the development of peel browning spots was closely related to reduced membrane lipid peroxidation, activities of LOX and PPO, and the expression of LOX1, PPO1, and PPO5 genes in peel tissue in pears.

Low-temperature storage has been tested to maintain sugar levels in harvested fruits. Depletion of soluble solids at high temperature can be explained by a high respiration rate. A decline in sucrose content was also observed in pears during storage, while the levels of fructose and glucose increased during 5 months of storage at 0 °C (Chen et al. 2006).

Controlled Atmosphere Storage and Modified Atmosphere Packaging

Recently, the packaging of highly perishable fruits in polymeric films with specific gas permeabilities, in combination with low-temperature storage, has gained importance (Kader and Watkins 2000; Steward et al. 1999). Many types of plastic films are available for packaging, but relatively few have been used to wrap fresh produce. Low-density polyethylene, polyvinyl chloride, and polypropylene have been the main films used to package fruits (Kader et al. 1989; Watkins 2000; Nath et al. 2012). Many storage techniques have been developed over the years to extend the storage life of fruits.

Controlled atmosphere (CA) refers to the introduction of low oxygen (O_2) and/or high carbon dioxide (CO_2) atmosphere to a container or an airtight enclosure holding the product. The atmosphere is 'controlled' by a sequence of measurements and corrections throughout the storage period and is used as a supplement to proper refrigerated storage and distribution. Controlled atmosphere has been used historically in large storage facilities, where the levels of atmospheric gases are continuously monitored and adjusted to maintain optimal concentrations. It is typically applied to commodities amenable to long-term storage, such as apples and pears. The use of CA is increasing due to improved cost-effectiveness in delivering extended shelf life and enhanced produce quality. However, this technology may affect the volatile composition of the room atmosphere, which, in turn, may affect the volatile production of ripe fruit. However, CO_2 injury, increased ethanol production, and flavor problems due to anaerobic respiration have been reported (Sun-XiSheng et al. 2000; Saquet et al. 2003; Drake et al. 2004).

Off-flavor compounds such as ethanol and acetaldehyde start to accumulate during long-term storage of pears in high CO_2 atmosphere that promotes the progression of physiological disorders, including core browning. It has been noticed that pears stored in CA with high CO_2 concentrations developed rapid injury. In CA-stored pears, H_2O_2 accumulated rapidly, indicating that fruits undergo stress from changes in O_2 and CO_2 concentrations. Short-term storage of 'Conference' pears under CA (2% O_2 and 5% CO_2) exhibited an increase in superoxide dismutase and ascorbate peroxidase activities, and a decrease in catalase activity (Larrigaudiere et al. 2001). Higher lipoxygenase enzyme activities were also reported in CA-stored pears, which induced membrane lipid peroxidation. CA storage can preserve health-promoting components in some cultivars, while high CO_2 concentration may reduce

the ascorbic acid content and antioxidant activity in some fruits, including strawberries and pears.

The dominant varieties of pears grown in Washington are Anjou, which is stored for up to 9 months in CA, and a Bartlett variety can be stored up to 3 months in CA. Bartlett pears should be considered mature to harvest starting at a firmness of 8.6 kg for CA storage and continuing to 7.7 kg for short-term storage. Anjou pears start at 6.8 kg firmness for CA storage and continue to 5.9 kg for short-term storage. Bosc pears start at 7.3 kg firmness for CA storage and continue to 6.4 kg for short-term storage. In all pears, it is important to monitor the starch level, because, in certain seasons, firmness will remain high for a time while the starch content changes. This starch change indicates a movement in maturity.

Modified atmosphere packaging (MAP) has been successfully used to maintain the quality and increase the shelf life of fruits. The successful use of MAP is based on the specific permeation properties of polymer films to O_2 and CO_2 to generate atmospheres that are suitable for the postharvest life of many horticultural commodities (Sandhu and Singh 2000; Dou-ShiJuan et al. 2002, 2003). This technology also provides three advantages: it helps to reduce browning, control postharvest diseases, and it maintains a high-humidity environment inside the sealed plastic film (Dou-ShiJuan et al. 2002; Kwon et al. 2003).

Wang and Sugar (2013a) studied the effect of MAP on 'Bartlett' pears during storage and transit. 'Bartlett' pears harvested at commercial maturity were packed in a commercial MAP (MAPc), an experimental MAP (MAPe), and commercial perforated plastic bags (control) and stored in air at −1.1 °C. After 1 and 3 months of storage, samples of MAPc and control fruits were transferred to rooms at temperatures of 2, 4.5, 7.5, and 10 °C for 3 weeks to simulate transit temperatures and the time required to reach distant markets. MAPc maintained an average internal atmosphere of 12.3% O_2 + 5.6% CO_2 and significantly extended 'Bartlett' pear storage life with high eating quality and without internal browning and other disorders for up to 4 months at −1.1 °C. The internal gas atmosphere of MAPe equilibrated at 2.2% O_2 + 5.7% CO_2, which resulted in fruit with 25.5 and 62.3% internal browning after 3 and 4 months of storage, respectively. During simulated transit conditions of 2, 4.5, 7.5, and 10 °C, the CO_2 level in MAPc was maintained at 5.6–7.9%, while O_2 was reduced dramatically to 10.5, 5.0, 2.5, and 1.0%, respectively. Internal browning developed at 7.5 and 10 °C but not at 2 and 4.5 °C, regardless of the pretransit storage duration (1 and 3 months) at −1.1 °C. The longer the storage duration and the higher the transit temperature, the higher the incidence and severity of internal browning. The MAPc storage gas atmospheres maintained fruit firmness, color, and higher eating quality after ripening, eliminated senescent scald and core breakdown, suppressed the loss of ascorbic acid and titratable acidity, and slowed the accumulation of malondialdehyde during storage at −1.1 °C for up to 4 months or 3 months + 3 weeks at simulated transit temperatures of 2 and 4.5 °C. In contrast, fruit held in MAP with low O_2 levels (1.0–2.5%) developed internal browning that appeared to be associated with a reduction in ascorbic acid, accumulated malondialdehyde, and exhibited an increase in membrane leakage. MAP inhibited ripening at high CO_2 + high O_2 but lead to internal browning when the packaging material or

elevated temperatures resulted in high CO_2 + low O_2 conditions. The incidence of internal browning closely correlated with lipid peroxidation and appeared to be related to fruit ascorbic acid concentration. The MAPc designed for pears appears to be suitable for 'Bartlett' fruit stored at −1.1 °C for up to 4 months or storage for 3 months and transportation duration of up to 3 weeks at 0–4.5 °C during the early season and at 0–2 °C during the late packing season.

The storage life of 'Comice' pears increased by up to 2 months when packed in MAP as compared with fruit packed in standard perforated polyethylene liners (Wang and Sugar 2013b). In this study, control fruit packed in standard perforated polyethylene liners started to show senescent core breakdown and lost the capacity to ripen at 20 °C after 4–5 months of cold storage. MAP inhibited ethylene production, ascorbic acid degradation and malondialdehyde accumulation, and extended the storage life for up to 6 months with maintenance of fruit flesh firmness and skin color without a commercially unacceptable level of physiological disorders. After 4, 5, and 6 months at −1 °C, MAP fruit exhibited climacteric-like patterns of ethylene production and softened to proper texture with desirable eating quality on day 5 during ripening at 20 °C. After 6 months at −1 °C plus 2 weeks of simulated transit conditions, MAP fruit maintained flesh firmness as well as skin color and had good eating quality at transit temperatures of 2 and 4.5 °C (10.1–11.5% O_2 + 4.8–5.2% CO_2), but reduced flesh firmness substantially and developed internal browning disorder at 7.5 and 20 °C (3.2–7.2% O_2 + 7.9–9.5% CO_2).

Anjou pears should be stored with the oxygen level at least 1% higher than the carbon dioxide level at all times, especially when the fruit is held at −0.5 to 1.0 °C. There has been some research that fruit stored at temperatures higher than 1 °C can tolerate higher CO_2 levels. Fruits stored with CO_2 levels 1% above the oxygen level had no internal browning, was greener, and had less skin marking than fruit stored at low CO_2 levels (Drake 1994).

Edible Coatings

Edible coatings, a new strategy to extend shelf life and improve food quality of whole fruits and fresh-cut fruits, have been applied to many products. They can provide a selective barrier to moisture, oxygen, and carbon dioxide gas transfer, which slows ripening, reduces moisture loss, and helps to maintain fresh aroma and flavor (Olivas and Barbosa-Canovas 2005). Edible coatings are also used as carriers of active ingredients, such as antibrowning, antimicrobial, and texture-enhancing compounds, as well as flavors and nutrients, to improve the quality, safety, and nutritional value of fresh-cut fruits (Rojas-Grau et al. 2009). Wang et al. (2017b) assessed the usefulness of postharvest coating of pear fruits with low molecular weight chitosan as a preservative agent. They reported that the chitosan coating had a significant preservative effect on wounded and non-wounded pear fruits, by inhibiting postharvest decay and browning processes. Chitosan coating activated several defense-related enzymes (polyphenol oxidase, peroxidase, chitinase), maintained nutritional value, and slowed down weight loss.

Zhou et al. (2011) investigated the effects of edible coatings, such as shellac and Semperfresh™ (sucrose polyester-based coating) on the brittleness and firmness of 'Huanghua' pears (*Pyrus pyrifolia* Nakai cv. Huanghua) for up to 60 days of cold storage (4 °C) after harvesting. The activities of peroxidase, pectinesterase, polygalacturonase, and cellulose were also assayed. The data suggested that high potassium sorbate activity and low activity of cell-wall-degrading enzymes, such as pectinesterase, polygalacturonase, and cellulose, in the coated pears were associated with a high integrity of the cell membrane and few changes in the cell-wall constituents, which contributed to high levels of brittleness and firmness in the pears during storage; further, the shellac coating provided a better effect than Semperfresh coating.

Kowalczyk et al. (2017) assessed the efficacy of a coating composed of carboxymethyl cellulose, candelilla wax, and potassium sorbate as a postharvest cold storage treatment to prevent fungal infections in pears stored under simulated retail display conditions. They reported that the coating was very effective against *Botrytis cinerea* and *Monilinia fructigena*, while *Rhizopus nigricans* was the most resistant to potassium sorbate. The potassium sorbate free coating also delayed the fungal growth rate, probably due to modification of the gaseous atmosphere within the fruit tissues. Coated pears showed slower ripening than the uncoated samples, as indicated by unaffected green skin color and inhibited loss of firmness. Unfortunately, the coating induced anaerobic respiration and the symptoms of superficial scald in pears. Overall, the results showed that potassium sorbate can be added into a coating formulation to control fungal growth; however, carboxymethyl cellulose-based emulsion is not a suitable carrier for potassium sorbate, when coating is intended to be applied to pears exposed to postharvest cold storage.

Fresh-cut pears have very high susceptibility to enzymatic browning and tissue softening after cutting (Sapers and Miller 1998). Recently, several studies have used chemical dip treatments with or without edible coating in the preservation of fresh and fresh-cut pears, in order to prevent cut surface discoloration, maintain tissue texture, reduce moisture loss, and inhibit the growth of microorganisms (Bai et al. 2009; Lin and Zhao 2007; Xiao et al. 2010).

The influences of xanthan gum-based edible coatings (2.5 g L^{-1}), applied alone or enriched with cinnamic acid (1 g L^{-1}), on the quality attributes of fresh-cut Asian pear (*Pyrus pyrifolia* L. cv. 'Nashpati') and European pear (*Pyrus communis* L. cv. 'Babughosha') stored at 4 °C was studied by Sharma and Rao (2015). They reported that the incorporation of cinnamic acid as an antioxidant agent into xanthan gum-based edible coating caused significant retardation of the oxidative browning, decline of the ascorbic acid level, degradation of the total phenolics content, and reduction in antioxidant capacity as compared to fresh-cut pears coated only with xanthan gum and uncoated ones. The control slices of 'Nashpati' displayed a greater rise in the browning index and polyphenol oxidase activity and consistent decline in lightness (L*) values than those of 'Babughosha' during 8 days of storage. Thus, the tested xanthan gum-based edible coating plus cinnamic acid may contribute to reducing the surface browning and enhancing the shelf life of fresh-cut 'Nashpati' and 'Babughosha' for 4 and 8 days, respectively, at 4 °C.

The quality and internal characteristics of Huanghua pears (*Pyrus pyrifolia* Nakai cv. Huanghua) treated with different kinds of coatings during storage was studied by Zhou et al. (2008).They used coatings with shellac, Semperfresh (sucrose polyester-based coating), and carboxymethyl cellulose during cold storage (4 °C). The changes in respiration rate, weight loss, cell membrane permeability, and texture profile analysis such as hardness, brittleness, and chewiness were recorded periodically for up to 60 days after harvest. They reported that shellac coating was more effective in reducing the respiration rate and weight loss and in maintaining the quality of pears than Semperfresh and carboxymethyl cellulose coatings.

The effect of alginate-based (2%, w/v), pectin-based (2%, w/v), and gellan-based (0.5%, w/v) edible coatings containing *N*-acetylcysteine at 0.75% (w/v) and glutathione at 0.75% (w/v) were studied on fresh-cut 'Flor de Invierno' pear quality for 14 days at 4 °C (Oms-Oliu et al. 2008). They reported that the use of polysaccharide-based edible coatings increased the water vapor resistance and reduced ethylene production of coated fresh-cut pears. The incorporation of *N*-acetylcysteine and glutathione into coating formulations not only reduced microbial growth compared with samples without antioxidants, but was also effective in preventing fresh-cut pears from browning for 2 weeks without affecting the firmness of fruit wedges. The increased vitamin C and total phenolic content observed in pear wedges coated with alginate, gellan, and pectin, including antioxidants, contributed to maintaining their antioxidant potential. In addition, coatings with alginate or pectin best maintained the sensory attributes of pear wedges for 14 days.

Xiao et al. (2011) studied the combined effects of sodium chlorite dip treatment and chitosan coatings on the quality of fresh-cut d'Anjou pears. Edible coatings were prepared from sodium chlorite alone, chitosan, and its water-soluble derivative carboxymethyl chitosan (CMCH), separately. Pear wedges were immersed in sodium chlorite solution, followed by coating with chitosan or CMCH solutions. The samples were packed in unsealed bags and stored at 4 °C for subsequent color, firmness, and weight loss measurement. The results indicated that sodium chlorite exhibited significant inhibition of browning and polyphenol oxidase activity. The sodium chlorite treatment was also strongly effective in inactivating *Escherichia coli* O157:H7 on pear slices. Coating sodium chlorite-treated pear slices with chitosan adversely affected the quality of pear slices by accelerating the discoloration of cut surfaces and increasing the polyphenol oxidase activity. On the contrary, coating sodium chlorite-treated samples with CMCH significantly prevented the browning reaction and inhibited polyphenol oxidase activity. In addition, sodium chlorite and chitosan/CMCH coatings maintained tissue firmness and did not affect weight loss.

Calcium plays an important role in maintaining the quality and storability of fruit and is well known to protect the integrity of cell membranes and to reduce membrane permeability (Bhat et al. 2012). Kou et al. (2015) evaluated the effects of postharvest dipping with 2% calcium chloride and coating with 1% pullulan on the development of brown spots during 8 months of cold storage at 0 °C. They reported that both treatments reduced the incidence of brown spots, inhibited the activities of polyphenol oxidase and peroxidase, increased the activities of catalase and superoxide dismutase, and delayed the loss of phenolic compounds, compared with

untreated controls. Concomitantly, concentrations of α-farnesene, conjugated trienes, and malondialdehyde were maintained at lower levels in most tissues of treated fruit compared with those of control fruit. These results suggest that both calcium chloride and pullulan treatments inhibited the development of brown spots on 'Huangguan' pear by delaying the loss of the polyphenol substances and maintaining the structural integrity of cell membrane.

1-Methylcyclopropene Treatment

Ethylene is a plant hormone that regulates plant growth and developmental processes, as well as ripening and senescence. The mode of action of ethylene may, thus, be influenced by the physiological status of the tissue. The production and continued action of ethylene are key factors that determine the shelf life and quality of harvested produce. Thus, several technologies have been developed with the objective of controlling these events. The use of ethylene receptor blocker 1-methylcyclopropene (1-MCP) is one of the latest technologies that has entered the market.

With the approval by the *Environmental Protection Agency* in 2002, 1-MCP is marketed under the trade name of SmartFresh. The use of SmartFresh has been approved by over 20 countries. The approval is for specific crops and includes apple, apricot, avocado, carrot, kiwifruit, mango, melon, nectarine, papaya, peach, pear, pepper, persimmon, pineapple, plantain, plum, squash, tomato, and tulip bulbs. At 20 °C, 1-MCP is released as a gas from a formulated cyclodextrin powder when it is mixed with water in nearly 20–30 min. A complete release may take longer duration at lower temperatures. Under such conditions, 1-MCP is absorbed by the harvested material over time.

1-MCP has been tested for its effectiveness on summer and winter pears. They require an exposure to chilling temperatures before they begin to ripen. Winter pears require as much as 8 weeks at low temperature before they ripen. Winter pears soften and develop a buttery texture, while summer pears better retain their crispiness after they ripen. 1-MCP treatment delayed or prevented softening; the degree of response depended on the cultivar and the concentration of 1-MCP applied (Trinchero et al. 2004). The soluble solids content was not affected in pears after 1-MCP application, while changes in the total acidity were inconsistent (Trinchero et al. 2004). In a sensory evaluation on 'Packham's Triumph' pears, the flavor and aroma profile of 1-MCP-treated fruit stored in air were preferred over CA-stored fruit (Moya-Leon et al. 2006).

There is variability in the concentrations of 1-MCP that delay but do not prevent pear ripening. Application of 0.2 μL L^{-1} resulted in normal ripening with no overripening (Moya-Leon et al. 2006), while concentrations as high as 10 μL L^{-1}resulted in the maintenance of optimal eating firmness for extended periods (Kubo et al. 2003). The efficiency of ethylene to reverse 1-MCP effects was dependent on the concentration of 1-MCP application and the length of time the fruit had been stored

(Ekman et al. 2004). In pear fruit, inhibition of ethylene production by 1-MCP was accompanied by lower expression of these genes (Defilippi et al. 2005). Conference pears were treated with 1-MCP and then stored in air and CA. After storage, fruits were retreated with 1-MCP. The 1-MCP effects were perceivable on texture (juiciness) and flavor. Control fruit and 1-MCP at 25 nL L^{-1}fruit reached their best sensory quality after 14 weeks of storage, while 50 nL L^{-1} fruit reached the same sensory quality later, keeping a fresh flavor when the quality of control fruit declined and became watery or grainy. CA storage prolonged or enhanced the effects of 1-MCP; however, 1-MCP cannot substitute for CA but can reinforce the CA effects (Rizzolo et al. 2005).

Lum et al. (2017) investigated the effect of 1-MCP and CA versus refrigerated air on the incidence of senescent scald and internal breakdown in pears of two genotypes, 'Swiss Bartlett' and 'Cold Snap'. Freshly harvested pears were treated with or without 1-MCP, and then stored at 0 °C under refrigerated air or CA (18 kPa or 2.5 kPa O_2, and 2 kPa CO_2) for at least 167 days. 1-MCP and CA delayed and/or reduced the rates of ethylene production in stored fruits of both cultivars. 1-MCP and CA delayed fruit softening and peel yellowing in 'Swiss Bartlett' pears, but had negligible effects on 'Cold Snap'. In both cultivars, high incidences of senescent scald and internal breakdown occurred in non-1-MCP-treated pears during refrigerated air storage. For the most part, these symptoms were reduced by CA and 1-MCP, resulting in minimal to negligible incidence in 1-MCP-treated pears stored at 2.5 kPa O_2.

The physiological and biochemical responses of 1-MCP-treated 'd'Anjou' pear fruit to different storage conditions were studied by Xie et al. (2014). In this study, 'd'Anjou' pears harvested at commercial and late maturity were treated with 1-MCP at 0.15 μL $L^{-1}$and stored either at the commercial storage temperature −1.1 °C (1-MCP@−1.1 °C) or at 1.1 °C (1-MCP@1.1 °C) or 2.2 °C (1-MCP@2.2 °C) for 8 months. Control fruit stored at −1.1 °C ripened and developed significant scald within 7 days at 20 °C following 3–5 months of storage. While 1-MCP@−1.1 °C fruit did not develop ripening capacity due to extremely low internal ethylene concentration and ethylene production rate for 8 months, 1-MCP@1.1 °C fruit produced significant amounts of internal ethylene concentration during storage and developed ripening capacity with relatively low levels of scald within 7 days at 20 °C following 6–8 months of storage. 1-MCP@2.2 °C fruit lost quality quickly during storage. Vanoli et al. (2016) studied the effect of 1-MCP (300 nL L^{-1}) treatment at two storage temperatures (−0.5 °C, 1 °C) on 'Abate Fetel' pears. They reported that 1-MCP treatment strongly reduced ethylene production in pears stored at −0.5 °C, inhibiting softening, yellowing, and the development of superficial scald, soft scald, and internal breakdown, regardless of the storage atmosphere and time.

Villalobos-Acuna et al. (2011) studied the effect of 1-MCP (0.3 μL L^{-1}) treatment on 'Bartlett' pears immediately after harvest in two seasons and four maturities. 1-MCP decreased the rates of softening, ethylene production, respiration, and yellow color development, and reduced the incidence of scald and internal breakdown. Ripening recovery induced by cold storage of 1-MCP-treated fruit

depended on maturity and season and was associated with stimulated ethylene production, including 1-aminocyclopropene carboxylic acid synthase activity, 1-aminocyclopropene carboxylic acid oxidase activity, and transcript levels of genes associated with these enzymes.

Combined effects of 1-MCP and MAP on the fruit quality of pear (*Pyrus bretschneideri* Reld cv. Laiyang) during cold storage was studied by Li et al. (2013). The results showed that 0.5 μL L^{-1}1-MCP plus microperforated film packaging maintained the color, firmness, titratable acidity, and vitamin C content of the fruit flesh and was the most appropriate treatment for the 'Laiyang' pear fruit cultivar during cold storage. Treatment with 0.5 μL L^{-1}1-MCP plus microperforated film packaging inhibited respiration and ethylene production; maintained the activity levels of super oxidase dismutase, peroxidase, and catalase; decreased the cell membrane permeability and malondialdehyde content; and inhibited the lipoxygenase and polyphenol oxidase activity of the fruit during cold storage.

Growth Regulator Treatment

The application of several pre- and postharvest treatments have been investigated to reduce the oxidative stress and to increase the nutritional value of the products. Pre- and postharvest treatments of fruits with plant growth regulators and natural volatile compounds have shown positive effects on antioxidant activity. Methyl jasmonate treatment enhances antioxidant activity and free radical scavenging capacity in fruits. During inadequate antioxidant activity, free radicals cause membrane deterioration, resulting in the progression of physiological disorders, including core browning (CB), in pears. A reduction in antioxidant enzymes (SOD, POX, and CAT) has been noticed in CB pears (Fu et al. 2007).

Postharvest Disorders

Physiological Disorders

Fruit disorders can occur at harvest, during storage, transit, and at the retail level. Once properly identified, remedial action can then be taken in the orchard, packing house, or retail store to correct and prevent any further occurrence of these disorders. Although fruit disorders are influenced by cultivar and climate, fundamental causes account for common features.

Scald

Pears can be classified broadly into two groups based on ripening characteristics. One group of pears, including Anjou, Winter Nelis, Packham's Triumph, and Hardy, do not lose their capacity for normal ripening as a result of extended storage. Anjou pears are susceptible to storage scald and, like apples, they respond to control measures with oil wraps, ethoxyquin, or diphenylamine. Low oxygen and high CO_2 treatments before storage are also effective for control measures for Anjou pear.

The other group of pears, which includes Bartlett, Bosc, Howell, Cornice, Sierra, and Flemish Beauty, lose their ability to ripen when stored for extended periods. The fruit turns yellow and eventually develops a dark brown discoloration of the skin called senescent scald. This may occur in cold storage or when the fruit is removed from cold storage and subjected to warm ripening. The fruit is inedible and remains firm, but the skin does slough off easily. Reducing the storage period is the only control measure available. In pears, initial low oxygen (0.7%), ethoxyquin drench, or ethoxyquin embedded in the paper wrapper are utilized to control scald.

Superficial Scald

Superficial scald is a low-temperature physiological disorder of certain apple and pear cultivars that develops during prolonged low-temperature storage. Typically, early-harvested and less mature fruits are most susceptible, but scald may also develop on fully mature fruit. The disorder appears as browning of the skin as a result of damage to the hypodermal cells. Scald development results from the production of α-farnesene and its auto-oxidation to conjugated trienols. Generally, correlations between conjugated triene concentration and scald occurrence are strong, but those between α-farnesene and scald are variable (Meir and Bramlage 1988). α-Farnesene typically increases rapidly during storage and then declines, while conjugated trienes continue to increase (Watkins et al. 1995).

The effect of 1-MCP has been thoroughly investigated for reducing physiological disorders of apples and pears that occur during storage. Several studies were in relation to superficial scald, since an interaction between ethylene production and α-farnesene was believed to be a primary cause of scald development, and early reports indicated that 1-MCP inhibited superficial scald development (Watkins et al. 2000). Superficial scald appears as a brown discoloration on the peel in apple and as black patches on pear. Superficial scald has also been termed as a chilling-injury symptom, as it occurs during low-temperature storage (Watkins et al. 1995). The accumulation of α-farnesene and its oxidation to conjugated trienols in the peel region and associated cell damage is believed to cause the development of this symptom (Whitaker et al. 1997). α-Farnesene production is enhanced by ethylene (Whitaker et al. 2000). Superficial scald can be prevented or alleviated by inhibiting α-farnesene production or its oxidation. It has been demonstrated that inhibition of

scald by 1-MCP is associated with inhibition of α-farnesene accumulation, and, therefore, less substrate for oxidation (Pechous et al. 2005).

Freezing/Chilling Injury

Pear fruits are also susceptible to many physiological disorders during cold storage, including superficial scald, senescent scald, and internal breakdown, which are symptoms of chilling injury (Drake et al. 2006; Whitaker et al. 2009). The development of superficial scald in 'Bartlett' pears was found to be associated with fast accumulation of α-farnesene and conjugated trienes (Whitaker et al. 2009). It is also well known in pear that 1-MCP can prevent or minimize these symptoms by reduction in ethylene, α-farnesene, and CTs (DeEll and Ehsani-Moghaddam 2011; Isidoro and Almeida 2006). It was suggested in 'Anjou' pears that 1-MCP controlled scald by inhibiting α-farnesene synthesis and oxidation, whereas the antiscald chemical ethoxyquin only inhibited α-farnesene oxidation (Bai et al. 2009). Edna et al. (2014) studied the effect of low oxygen (0.5%) prestorage treatment for reducing chilling injuries of pear fruit. The research findings showed that low O_2 pretreatment applied to Californian 'Bartlett' or Israeli 'Spadona' pears was effective in reducing superficial scald, senescent scald, and internal breakdown after 4–4.5 months of cold storage at −1 °C or 0 °C, respectively, plus 5–7 days at 20 °C.

Long exposure to mild freezing temperatures results in a layer of healthy tissue immediately below the skin, followed by a layer of water-soaked tissue. The cortical tissue in such fruit shows brown vascular bundles, with brown cortical tissue in more severe cases. Severe freezing causes cavitation in the cortex. Freezing points in pears depend on the quantity of dissolved sugars and electrolytes in the cytoplasm; the freezing point among Bartlett pears can differ by as much as 1 °C. A soluble solids content of less than 8% in Bartlett pears has resulted in a freezing point of −1.2 °C. Most pears, however, have a freezing point of −2 °C or lower.

Alfalfa Greening

This disorder, also known as green stain, is confined to Anjou pears grown in the Pacific Northwest and is characterized by dark green specks, blotches, or longitudinal streaks on the skin, particularly around the stem area. Even though dessert quality is not altered, the fruit is culled commercially. Skin staining begins 3–6 weeks before harvest. Fruit with the disorder has higher levels of N, P, and K and lower levels of Ca than sound fruit. High N:Ca ratios and frequent irrigation are conducive to the disorder. Calcium sprays are beneficial, but high concentrations can cause appreciable skin injury. Slow drying conditions or high temperatures during spraying render the fruit and leaves more sensitive to spray injury. Superficial cork often accompanies alfalfa greening, as both are associated with a low calcium content in the fruit (Meheriuk et al. 1994).

Bitter Pit

Bitter pit (also known as cork spot and Anjou pit) in pears is an abnormality in the cortical tissue. It develops during the latter part of the growing season and is quite similar to bitter pit in apples. Patches of corky brown tissue, usually near the calyx end, occur deep in the tissue or immediately under the skin and appear externally as dark green sunken areas. Affected fruit becomes partly yellow and softens prematurely, even in storage. Anjou and Packham's Triumph pears are highly susceptible to cork spot. Cultural practices that minimize bitter pit in apples are also effective for cork in pears. Tissue prone to cork is low in calcium or has a high K:Ca ratio, respires more intensely, produces more ethylene, and has a higher chlorogenic acid content in the skin. High rates of nitrogen application increase the incidence of the disorder. Calcium sprays have a beneficial effect on the prevention of cork spot; late sprays are more effective than early sprays and multiple sprays are more effective than single sprays. Efficacy depends on concentration, but the risk of phytotoxicity also increases (Meheriuk et al. 1994). Raese and Drake (2006) studied calcium foliar sprays for the control of alfalfa greening, cork spot, and hard end in 'Anjou' pears. The application of calcium spray had the lowest incidence of bitter pit.

Black End

This disorder, restricted to pears, is often characterized by a black discoloration of the calyx end. The calyx end may become peaked or flattened; the epidermal tissue is tight and glossy. Studies suggest that the disorder is initiated 45–60 days after full bloom. Black spots may extend to the stem end in severe cases, and cracks to the core area in the calyx area may be present. Hard end is another manifestation of black end, but no discoloration occurs in the calyx area. Affected tissue remains hard, very gritty, and seldom softens upon ripening. Fruit with the disorder is smaller and grows more slowly; tissue in the calyx area is lower in Ca and B, higher in polyphenol oxidase activity, and higher in soluble solids content. Fruit grown on *Pyrus serotina* rootstock is more prone to the disorder than on other rootstocks. No leaf symptoms are evident in trees with black end fruit, but such trees have a tendency to bear black end fruit each year. Cultivars susceptible to the disorder are Anjou, Bartlett, Winter Nelis, Flemish Beauty, Cornice, Easter, and Clairgeau; susceptibility may differ with growing area (Meheriuk et al. 1994).

Carbon Dioxide Injury

Pears are considerably less tolerant to CO_2 than apples. Injury is first evident as browning of the interior carpel walls. As the disorder progresses, the core tissue adjacent to the carpels turns brown. More extensive injury of cortical tissue turns the tissue light brown in unripened fruit. As desiccation proceeds, cavities develop that

may be either small and scattered or large enough for a depression on the surface to occur. Skin and subepidermal tissue are rarely affected (Meheriuk et al. 1994).

Brown core in Anjou pears consists of brown core tissue interspersed with cavities. Pithy brown core in Bosc pear is similar to Anjou brown core, but core and cortical tissue may contain cavities. CO_2 injury in Bartlett affects core tissue next to the vascular region but outside the core line. Anjou pears stored in controlled atmospheres have recently suffered a disorder that produces small brown necrotic lesions on the skin. This disorder is associated with advanced maturity. The susceptibility of pears to CO_2 injury increases with advanced fruit maturity, delayed storage, slow cooling, high storage temperatures, prolonged storage, and low oxygen levels in the atmosphere. Fruit from trees of low vigor and fruit grown in cool seasons are quite sensitive to CO_2. Injury for a given CO_2 level is negatively correlated to the oxygen content of the atmosphere. In pears, high CO_2 caused succinic and citric acids to accumulate (Williams and Patterson 1964). Many other reports indicate changes in the organic acid metabolism in various plant species due to excess CO_2.

Low-Oxygen Injury

Low-oxygen injury of pears has been reported only once. Late-harvested Bosc pears in Oregon developed core browning during storage at 1%. Fruit picked at the correct maturity did not show any signs of core browning under the same storage conditions. It was, therefore, suggested that the late-harvested fruit had suffered a form of low-oxygen injury.

Chemical Injury

During handling and storage, pears may be exposed to some chemicals that could be injurious through misuse or because of fruit sensitivity. Current postharvest practices for pears include the use of scald-inhibiting chemicals, fungicides, calcium salts to control breakdown and bitter pit, salts to increase fruit buoyancy in flotation systems, detergents to clean fruit, and waxes to enhance appearance (Meheriuk et al. 1994).

Calcium Salts

Anjou pears sprayed with $CaCl_2$ to control cork spot in the fruit can develop surface marking because of sensitivity to the salt. The incidence of marking is reduced significantly when lower concentrations of the salt are combined with a surfactant. Dips in $CaCl_2$ solutions to retain fruit quality in Bartlett pears have resulted in external black necrotic spots and skin discoloration similar to scald (Meheriuk et al. 1994).

Many physiological disorders such as cork spot of pears, alfalfa greening of pears, internal breakdown, low-temperature breakdown, senescence breakdown,

water core, and superficial scald are associated with low levels of fruit Ca (Omala and Trzak 1994). Calcium has received considerable attention not only for its relationship to physiological disorders, but also for its other beneficial effects in extending the storage life of the fruit, delaying softening, and improving internal quality (Poovaiah 1993; Raese 1994; Occhi and Mignani 1995).

Ethoxyquin

Injury in the form of pinkish or black lesions has been reported for Anjou pears treated with ethoxyquin. In Oregon, concentrations of 1350 ppm or more were occasionally phytotoxic to Anjou pears. It is believed that injury can be attributed to solution concentration at points of contact after dipping (Meheriuk et al. 1994).

Cell Wall Degradation

Cell wall degradation is the major factor that causes softening of several fruits. This involves the degradation of cellulose and pectin components, or both. Cellulose is degraded by the enzyme cellulase or β-1,4-glucanase. Pectin degradation involves the enzymes pectin methylesterase, polygalacturonase (pectinase), and β-galactosidase. The degradation of cell wall can be reduced by the application of calcium as a spray or drench in apple and pear fruits. Calcium binds and cross-links the free carboxylic groups of polygalacturonic acid components in pectin. Calcium treatment, therefore, also enhances the firmness of the fruits. Polygalacturonase activity increases as the fruit ripens. The ripening fruits that possess both polygalacturonase and pectin methyl esterase do not develop mealy symptoms when stored at low temperature, implicating the potential role of pectin degradation in the development of mealiness in fruits. There are two forms of polygalacturonases in fruits: the exo- and endopolygalacturonases. In general, fruits such as peaches, tomatoes, strawberries, and pears, which soften extensively, possess high levels of endopolygalacturonase activity.

In pears, cell wall degradation is correlated with a decrease in firmness during ripening, and the modification of both pectin and hemicellulose are essential for the development of a melting texture. Different softening behaviors during ripening among the pear fruits may be caused by different endopolygalacturonase activity and different expression of polygalacturonase genes (Hiwasa et al. 2004). The increase in the activities of β-galactosidase and α-L-arabinofuranosidase during pear ripening correlated well with a concomitant decrease in flesh firmness. The β-galactosidase and α-L-arabinofuranosidase may not mediate differences in fruit softening between two pears, but they could play some role(s) in cell wall changes, perhaps in cooperation with other cell wall-modifying enzymes, such as polygalacturonase (Mwaniki et al. 2007).

Core Breakdown

Core breakdown is a senescent disorder in which core tissue becomes brown, watery, and, in the case of Bartlett, easily separated from the healthy tissue. The main vascular elements also turn dark brown. Breakdown in Bosc pears that have been stored for long periods may be preceded by vascular browning as the fruits ripen at room temperature. Factors that influence core breakdown are crop load, harvest date, storage temperature, delayed cooling, and delayed storage. Treatments that reduce core breakdown in Bartlett pears are calcium dips, high CO_2, and heat. A causal relationship has been suggested for acetaldehyde accumulation and core breakdown in Bartlett pears. The time between ripening and the occurrence of breakdown is important to the processor and the consumer. This interval, which may be a week or more in fruit ripened soon after harvest, decreases with late harvesting, adverse storage conditions, or extended storage. When cultivars such as Bartlett and Bosc, which ordinarily do not ripen at low temperatures, are kept too long in cold storage and then transferred to room temperature (20 °C) for several days, core breakdown may occur before the fruit has fully ripened. Yellowing of pears during storage is often a good indication of high susceptibility to core breakdown. Further storage often leads to the development of senescent scald and a complete inability to ripen. Other cultivars, such as Anjou, Packham's Triumph, and Winter Nelis, which are capable of ripening slowly at low temperature, may develop core breakdown in cold storage (Meheriuk et al. 1994).

Controlled atmosphere storage extends the storage life of pears and, thus, reduces the development of core breakdown. Some late-picked Bartlett pears in California developed a watery breakdown when stored at higher temperatures or were delayed in cooling.

Friction Marking

Most plant cells undergo enzymatic browning when injury exposes the cell contents to oxygen. Browning of injured fruit results from a reaction of polyphenol oxidase with naturally occurring phenols, such as chlorogenic acid and catechol, in the presence of oxygen. The brown-colored products of these reactions are ortho-quinones, which polymerize to form more intensely colored substances. Skin abrasions caused by handling, packing, or transit may result in browning of the skin and the underlying tissue of pears, apples, apricots, and peaches. Pears are very susceptible, often sustaining friction marking by the movement of one fruit against another or against the sides of bulk bins. Such abrasion can take place in the orchard, during packing, or in transit. The extent of friction marking in pears is related to the chlorogenic acid content in the skin (Meheriuk et al. 1994).

The concentration of phenolics in the skin of Anjou pears declines with advancing fruit maturity but increases again during storage. This finding is consistent with the observation that small pears picked early scuff more readily than mature fruit

and that later packing of pears is likely to result in a higher incidence of friction marking than earlier packing (Meheriuk et al. 1994).

Antioxidants such as ascorbic acid, sulfur dioxide, and the enzyme inhibitor 2-mercaptobenzothiazole reduce or prevent browning of pear skin. High CO_2 treatments and surface-coating materials also reduce the incidence of friction marking in pears. At present, however, no chemicals are permitted for the control of friction marking of pears. The most effective way to minimize friction marking of pears is to modify handling and packing procedures. For example, use greater care in moving fruit containers in the orchard; use bulk bins with rigid bottoms; if necessary, line the sides of bins with a smooth material; reduce the speed of brushes when the fruit is being cleaned or dispense with brushes on the packing line; and make sure that the fruit packs are tight enough to prevent movement of fruit during transit. Less friction marking occurs on pears that are picked at the correct maturity and are packed within 3–4 weeks of harvest. If they are packed directly from cold storage, do not warm them before packing. Such a procedure is likely to increase scuffing and reduce storage life. Avoid unnecessary drying of pears because water lubricates the fruit on the packing line. Because polyphenol oxidase is less active under acidic conditions, therefore, it is advisable to avoid the use of alkaline salts in flotation systems for pears (Meheriuk et al. 1994).

Pink End

When cold weather occurs in the latter part of the growing season, Bartlett pears sometimes begin ripening on the tree before the usual harvest time. The disorder is routinely called pink end but is also known as premature ripening. Early yellowing of fruit at the calyx basin, accelerated softening, and pink coloring of the fleshy calyx (pink end) indicate premature ripening. Serious losses can occur unless the fruit is harvested at the first signs of ripening, cooled quickly, and sold promptly. Depending on the severity of the disorder, harvested fruit may continue to ripen and undergo complete breakdown if the fruit is placed in warm temperatures after cold storage (Sharma et al. 2009).

Breakdown associated with premature ripening is somewhat different from core or senescent breakdown. It occurs at the calyx basin, where the soft light brown color of affected tissue is clearly visible through the skin of the fruit, in contrast to core breakdown, which is not visible externally (Sharma et al. 2009).

Pink end can be initiated when night temperatures of about 7 °C or lower occur during the last 4 weeks of fruit growth. When day temperatures are 20 °C or lower, the accumulation of about 25 h of night temperatures of 7 °C or lower is sufficient to stimulate ethylene production and the onset of fruit ripening. When day temperatures are higher than 20 °C, a longer exposure to chilling is required to initiate ripening, or premature ripening may be averted entirely. Gibberellic acid applied about 4 weeks before harvest counteracts the effect of low temperature.

Microbiological Disorders

Stony Pit

Stony pit, a viral disease of pears, may occur in any region where pears are grown. Commercially important losses, however, appear to be confined to the Pacific coast area. The Bosc variety is most subject to stony pit, but the disease also affects cultivars like Anjou, Winter Nelis, Hardy, and Forelle. In affected fruit, masses of stone cells occur in the flesh of pears at the bottoms of dimple-like depressions. The lumps of stone cells are so hard that it is almost impossible to cut them. When the pitting is severe and the pits are numerous, fruits may be greatly distorted. Seriously affected fruits are worthless. Fruits that are only slightly pitted, however, are often marketed (Sharma et al. 2009).

Bioagents in Managing Postharvest Diseases

Among the control measures, the chemical method is one of the common practices due to its efficacy and low cost. However, it has some residual effects on the produce that leads to environmental pollution, health hazards to the consumers, and development of some resistant strains of pathogens against some chemicals. So, the global trend is shifting towards reduced pesticide use in agriculture in general and in postharvest in particular. Thus, biological control has emerged as an alternative method for postharvest disease management. As wound-invading necrotrophic pathogens are vulnerable to biocontrol, antagonists can be applied directly to the targeted area (fruit wounds), which significantly reduces fruit decays (Janisiewicz and Korsten 2002).

Most postharvest diseases in pear fruit are initiated at wounds that occur during harvest or packing. Subsequent infection occurs at the wound by one of several pathogens (Spotts et al. 1998; Sugar and Spotts 1993). Several microorganisms have been discovered that are able to colonize wound sites and compete with and reduce pathogen establishment at those sites. *Cryptococcus infirmo-miniatus* strain YY6, *Rhodotorula glutinis* strain HRB6 (Chand-Goyal and Spotts 1996a), and *Cryptococcus laurentii* strain RR87-108 (Roberts 1990) are yeasts that were originally isolated from the surfaces of pear or apple fruit in the Pacific Northwest. When inoculated into wounds on pears and apples after harvest in combination with pathogens, these yeasts have provided good control of rots caused by *Penicillium expansum*, *Botrytis cinerea*, and *Phialophora malorum* (Chand-Goyal and Spotts 1996a; Roberts 1990; Sugar et al. 1994; Sugar and Spotts 1999). *Candida oleophila* strain I-182 has also been effective in reducing postharvest decay (Hofstein et al. 1994) and is the active component of the biological fungicide Aspire (Ecogen Corp., Langhorne, PA), which is registered for postharvest use on pear.

While several studies have demonstrated the potential for biocontrol of postharvest disease when applied after harvest, few have addressed the practicality of applying biocontrol agents to the fruit while in the field with the purpose of controlling postharvest decays. Spotts and Chand-Goyal (1997) found that *C. infirmo-miniatus*

and *C. laurentii* reduced blue mold decay when applied to pear wounds 24 h after inoculation with *P. expansum*, but after 72 h, only provided control when combined with a fungicide. This indicates the importance of prompt application of biocontrol agents and the potential value of applying biocontrol agents in the field prior to the incidence of wounding during harvest (Spotts et al. 1998). An important consideration in the preharvest application of biocontrol agents is the ability of the microorganisms to survive at sufficient populations on the fruit surface after application. The weather in pear-growing regions is generally hot and dry in the preharvest period, which may have detrimental effects on yeast populations. Yeast may also be adversely affected by pesticide sprays (Chand-Goyal and Spotts 1996b) or washed off the fruit surface during irrigation or spraying. However, since these yeasts were originally isolated from fruit surfaces after or near harvest (Chand-Goyal and Spotts 1996a; Roberts 1990), they might be tolerant of these conditions. Some yeasts can colonize plant surfaces or wounds for long periods under dry conditions and produce extracellular polysaccharides that enhance their survival and restrict pathogen colonization sites (Janisiewicz 1988; Wisniewski and Wilson 1992).

Wound-invading necrotrophic fungi such as *Penicillium expansum* and *B. cinerea*, which cause postharvest blue mold and gray mold on apples and pears, respectively, require nutrients for germination and initiation of the pathogenic process. This requirement makes them suitable for biocontrol through nutrient competition. The pome fruit system is well suited for biocontrol, and many successful attempts have been reported from various laboratories (Chand-Goyal and Spotts 1996a, 1997; Qing and Shiping 2001; Usall et al. 2000; Wisniewski et al. 1995). In addition, decay was reduced significantly after preharvest orchard application of antagonists, which allowed antagonist populations to become established on fruit surfaces before anticipated wounding during harvest (Benbow and Sugar 1999; Teixido et al. 1999).

Biocontrol agents are more acceptable if they can be applied together with current practices, and information on the compatibility of the biocontrol agents with chemicals used in the postharvest system, e.g., antioxidant diphenylamine used for the control of superficial scald of apple, a physiological disorder, or flotation salts used to increase the buoyancy of pears during handling in water, should be developed. Additional criteria may include resistance to environmental stress in the orchard application of biocontrol agents (Benbow and Sugar 1999; Teixido et al. 1999; Ippolito and Nigro 2000) and pathogenicity of the antagonists to fruits, since strains of some antagonists with good biocontrol potential, e.g., *Aureobasidium pullulans*, can cause minor decay and russeting on some fruits (Matteson Heidenreich et al. 1997).

Conclusion

Pear is an important fruits crop, popular with the consumers for its unique fragrance, subtle aroma, sweetness, crispness, and a typical fruit of temperate climates, with delicate, pleasant, and smooth taste, and has a wide acceptance throughout the world. During storage, its shelf life is subject to decay, mechanical damage, and

moisture and nutritional losses. Important factors which influence the quality after harvest of pears are storage temperature, response to ethylene in ripening, gene expression, cell wall degradation, application of 1-MCP technology, and growth regulator treatments.

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Postharvest Biology and Technology of Quince

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Introduction

Quince (*Cydonia oblonga*) is a member of the Rosaceae family, which includes commercially important fruits such as apples and pears (Wojdyło et al. 2013). It is a climacteric fruit which is usually pear or oval shaped, bright yellowish in color, with typical flavor and aroma (Monka et al. 2014). Different varieties of quince are cultivated in 56 countries and there are more than 70 known genotypes of the quince in the world. The total world production of quince was estimated to be 596,532 metric tons and the major producers are China, Iran, Uzbekistan, and Turkey (FAOSTAT 2017).

Quince fruits are sour, astringent, hard, and woody; hence, they are not appreciated for fresh consumption. However, they can be consumed on full ripening and have a pleasant, lasting, and powerful flavor. Quince can also be consumed in cooked, dried, or processed form, like jam, jelly, juices, candies, marmalades, pies, and cakes (Silva et al. 2002, 2005a, 2006). Quince fruit mainly constitutes water and carbohydrates, and is a rich source of fiber. Other small constituents include proteins (0.4%), fats (0.6%), fiber (1.90%), potassium, vitamin C, and vitamin A (Moreira et al. 2008). It is also an important source of organic acids and phenolic compounds (Hamauzu et al. 2006). Minerals like sodium, potassium, calcium, magnesium, phosphorus, iron, copper, and zinc have also been found in quince fruits (Bíró and Lindner 1999; Souci et al. 2008).

Although quinces have a hard peel, these are vulnerable to spoilage under improper storage conditions associated with pathogenic disorders and wounds (Yurdugul 2005). As a climacteric fruit, quince is expected to continue ripening

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even after harvesting. Thus, during storage, fruit show gradual softening, change in green skin color in parallel with ethylene production, and loss of acidity (Nanos et al. 2015). Quince fruit can be stored for up to 5 or 6 months at 2 ± 1 °C, 85% RH (Tuna-Gunes and Koksal 2005). The storage requirements are different for different varieties of quince (KeLi 1988). Storage life, quality, and susceptibility to diseases and pathological disorders can be modified greatly by the soil type and cultural conditions (Gautier 1984). Thus, the choice of the best storage conditions requires information on how the cultivars behave locally and the soil conditions. Flesh browning is the most important quality problem of quinces during ripening and storage, as it affects consumer preference and results in crop loss (Gunes 2008). Earlier-maturing cultivars are more susceptible to flesh browning during storage than late-maturing cultivars (Tuna-Gunes and Koksal 2005). Some postharvest treatments have been tested to delay ripening, improve keeping quality, and decrease flesh browning, such as controlled atmosphere storage, coatings, etc. Besides, temperature is regarded as the most important factor controlling the postharvest metabolic reactions, microbial growth, and transpiration. Thus, cold storage processing has gained extra importance in extending shelf life by retarding the growth of microorganisms, postharvest metabolic activities, and moisture loss (Yurdugul 2005).

Nutritional Composition

Quince mainly constitutes water 84%, carbohydraates 10.6% (wet basis), proteins 0.4%, fat 0.6%. It also contains tannins at 0.8% level. (Moreira et al. 2008; Sharma et al. 2011). It is also an important source of organic acids (phytic, malic, and quinic) and functional components like phenolic compounds (flavonoids, rutin, and chlorogenic acid) with antioxidant activity, due to which quince fruits are gaining interest (Fattouch et al. 2007; Leonel et al. 2016). It is a good source of vitamin A (5.5 mg/100 g), thiamine (30 μg/100 g), riboflavin (30 mg/100 g), and niacin (0.2 mg/100 g). Minerals like sodium (9.2 mg/100 g), potassium (189 mg/100 g), calcium (66 mg/100 g), magnesium (10 mg/100 g), phosphorus (25 mg/100 g), iron (1.1 mg/100 g), copper (0.006 mg/100 g), and zinc (0.013 mg/100 g) have also been found in quince fruits (Bíró and Lindner 1999; Souci et al. 2008). Also, quince has α-amylase inhibition activity, which indicates its potential in food and pharmaceutical industries as a raw material (Leonel et al. 2016).

Quince is rich in polyphenolic compounds, especially procyanidins (Nagahora et al. 2013). These polyphenols have been identified and isolated from different parts of plants, such as leaves, fruits, seeds, stem, bark, and roots (Sajid et al. 2015). A total of 26 polyphenolic compounds were obtained from quince tissues (Wojdyło et al. 2013), which include: nine flavan-3-ols including [(-)-epicatechin, procyanidin B_2, three procyanidin dimers and trimers, and one tetramer], eight hydroxycinnamates (derivatives of caffeoylquinic and coumaroylquinic acid), and nine

kaempferol and quercetin derivatives. The total polyphenolic content ranged between 1709 and 3437 mg/100 g dry weight. The major class of quince polyphenols is constituted by flavan-3-ols, which represents approximately 78–94% of the total polyphenols (Hegedus et al. 2013). Quince seed polyphenols are 3-O-caffeoylquinic, 4-O-caffeoylquinic, 5-O-caffeoylquinic and 3,5-dicaffeoylquinic acids, lucenin-2, vicenin-2, stellarin-2, isoschaftoside, schaftoside, 6-C-pentosyl-8-C-glucosyl chrysoeriol, and 6-C-glycosyl-8-C-pentosyl chrysoeriol (Hamauzu et al. 2005; Silva et al. 2005b; Khoubnasabjafari and Jouyban 2011). Quince pulp has a chemical profile of six main phenolic compounds, of which 5-ocaffeoylquinic acid is the most abundant. Quince peel comprises about 13 phenolics and the predominant one is quercetin-3-O-rutinoside (Silva et al. 2005b). It was estimated that the total amount of phenolic compounds ranged from 40 to 100 mg/100 g in the pulp and 200–430 mg/100 g in the peel (Legua et al. 2013).

Maturity and Ripening

Maturity is one of the most important parameters of grade standard of a commodity. It is a stage of complete development of fruit tissue, after which it will start ripening. During the maturation process, the fruits receive a continuous supply of food material from the plant. On completion of maturation, an abscission or corky layer is formed on the stem end, which stops the inflow of food material. As a result, fruit depends on its own food reserves. Starch initially rises and then decreases, which is accompanied by an increase in soluble solids. The acid level also decreases as the sugar/acid ratio increases, as a result of which sweetness increases. Maturity at the time of harvest is the most important factor which governs the final fruit quality and storage life. Immature fruits are susceptible to mechanical damage and shriveling, and are of poor flavor quality when ripe (Kader 1999).

All fruits require a ripening process to attain optimal readiness for consumption. This process of ripening is usually denoted by changes in color, texture (usually softness), and flavor. However, climacteric fruits including quince are picked mature but unripe in order to withstand postharvest handling and long-distance shipping (Kader 1999). These fruits are capable of continuing their ripening process even after harvesting. This is due to the production of large quantities of ethylene by these fruits and ethylene exposure will result in faster and more uniform ripening. Thus, maturity indices are important factors for deciding when a commodity should be harvested to ensure acceptable eating quality to the consumer and to provide marketing flexibility. However, the necessity of long-distance shipment of fruits has resulted in early harvesting before ideal maturity. This, in turn, results in a less optimum quality product to the consumer.

Quince fruit cultivars ‘Vidoja’ and ‘Isfahan’ were harvested on 6, 14, and 21 October 2015 and 2016 and then stored at 0 ± 1 °C with 90 ± 5% RH for 5 months. The properties were measured immediately after harvest and at 1-month intervals

after storage. The delay in harvesting and prolongation of storage led to increasing of the total soluble solids and weight loss, and declining of firmness and phenols, titratable acids, and pectins. Until the third month of storage, there was no surface browning. Browning symptoms were observed from the fourth month of storage and increased in the fifth month up to 1.72%. Generally, the best harvesting time for 'Vidoja' was 185 days and, for the rest of the genotypes, it was 193 days after full bloom. Fruit storage for 4 months in the cold is advisable for these cultivars and genotypes (Tatari and Mousavi 2017).

Quince should be picked when they are firm, full sized, and should have reached final coloration (greenish yellow). When the stem pulls easily away from the branch, this means that they are ready to be picked. If it needs a large effort to pull out the fruit, then it may not be ready to harvest. During harvest, care should be taken to prevent the stem breaking off the fruit, otherwise it will act as a wound on quince and, in turn, will reduce its shelf life/storage period. Quince harvesting lasts from September to mid October (Carmen et al. 2015). Producers generally use objective methods to determine the harvesting date, which include the Magness–Taylor pressure tester or penetrometer testing. Those fruits planned for short-term storage or immediate marketing should be harvested at the minimal pressure range, while those planned for long-term storage and distant marketing should be harvested at the upper pressure range. Other maturity indicators include color, which should be greenish yellow at the time of harvest, furry grayish hairs which disappear with fruit ripening, soluble solids (10–16% depending on variety and growing location), and acidity (ranging from 40 to 79 mg ascorbic acid/100 g). Quince has a shelf life of 14 days at room temperature from the date of reception and is edible only when it becomes fully ripe. Quince requires a temperature of 20 °C for proper ripening (Sharma et al. 2011). The ideal appearance criteria for consumer acceptability of quince should be:

Color: Greenish yellow to yellow skin; pale to golden yellow flesh.

Visual appearance: Smooth thin skin with a clean-cut stem attached; free from foreign matter.

Sensory: Hard flesh, rather dry, and astringent or non-astringent; delicate apple fragrance; browns rapidly once cut; free from foreign or off-flavors and tastes.

Shape: Approximately oval, sometimes swollen/elongated around calyx or blossom end; no fruit with protruding areas or sutures.

Maturity: Firm, full-colored fruit.

Refrigerated Storage

The most widely used method for extending the storage life of fruits and vegetables is refrigeration. Low temperatures slow down the metabolism of the product and the activity of microorganisms, which are responsible for quality deterioration. Thus, refrigerated storage maintains the lower respiration rate; as a result, ethylene

production is minimized, which, in turn, retards the ripening process. Vapor pressure between the products and ambient atmosphere is also minimized, thus reducing the water loss (El-Ramady et al. 2015). All these factors maintain the quality, nutritional value, and freshness of the products. A refrigerated room should be thermally insulated and airtight; however, there should be a provision to release the heat generated by the product. Adequate airflow is required to distribute refrigerated air and maintain uniform air temperature throughout the room. It is important to control the temperature and relative humidity inside the cold rooms. This can be done by the intermittent operation of fans or by reducing the speed of fans. Slow air speed reduces the loss of moisture from the product (Kroca and Hellickson 1993). The storage life of quince fruits could be extended up to 2–3 months at temperatures 31–32 °F (−0.6 to 0 °C) with a relative humidity of 90–95% (WFLO 2008). Cold storage of quinces for 120 days at 2 °C results in decrease in firmness, density, pectin concentration, and titratable acidity, while there was increase in pH, weight loss, soluble solid content, and carbohydrate concentration (Moradi et al. 2017). Cold storage also provides high sensory qualities and lower microbial count by reducing their log cycle, thus providing adequate preservation under normal conditions (Yurdugul 2005).The characteristics of fresh quince fruit were also observed at 1 °C and 85% RH and at 5 °C and 80% RH. The results showed that the characteristics of quince fruit were ideally preserved at 1 °C even during 2 months of storage; afterwards, a significant loss was observed. This was followed by browning of fruit skin, change in aroma, decrease in vitamin C content, and increase in juice turbidity. However, at 5 °C, prominent changes were observed in all parameters during the complete period of storage. Quince can be stored for 4 weeks at 5 °C without significant internal quality (browning rate of fruit flesh, titratable acidity, ascorbic acid content, etc.) loss, while at 1 °C, the storage period can be extended up to 9 weeks (Vila et al. 2003).

Controlled Atmosphere Storage

This storage approach is made up of gastight chambers with insulated walls, ceiling, and floor. They are increasingly used for fruit storage on a larger scale. Modification of gas atmosphere may reduce the respiration rate of fresh produce and control the level of ethylene, thus retarding ripening. Depending on the fruit variety, various blends of O_2, CO_2, and N_2 are required. All controlled atmosphere (CA) rooms should be leak tested by competent personnel every year prior to loading. All leaks should be repaired until the room is sufficiently tight. Floor bumpers should be installed if not already present. Safety inspection of the storage facility should also be made from time to time (Swindeman 2002).Controlled atmosphere conditions at 2% O_2 + 3% CO_2 and 5% O_2 + 5% CO_2 at temperature 2 ± 1 °C can extend the storage life of quinces up to 7 months (Gunes 2008). At the 5% level (O_2 + CO_2 each) of storage conditions, ripening was accelerated and up to 80% higher flesh browning was observed by the end of storage. A study on two quince cultivars ‘Cukurgobek’

and ‘Esme’ showed different performance under CA conditions. Cukurgobek (the earlier cultivar compared to Esme), showed a rapid loss in firmness, fructose content, and sensory evaluation, and an increase in flesh browning (Gunes 2010).

The respiration rate of Chinese quince was measured at 0 and 10 °C to determine its tolerable range of storage temperatures. Chinese quince wrapped in highly gas-permeable polyolefin film attained, with progressive decreases in volume, 9.5–10.2% O_2 and 1.3–1.8% CO_2 at 0 °C, and 8.1% O_2 and 2.4% CO_2 at 10 °C. These levels preserve the fruit at acceptable quality levels for 152 and 50 days at 0 and 10 °C, respectively (An and Lee 2006).

Packaging

Fruits have high moisture content, ranging from 70 to 90% and, thus, the primary objective of packaging is to protect the fruits from normal atmosphere, so as to prevent their rapid drying, which can cause the shrinkage of cells, which, in turn, could result in shriveling and wilting. Packaging also aims to protect fruits against deterioration of the physical, chemical, or biological types. Packaging is provided either at the production or processing sites or at distribution centers. Quince is generally packed in gunny sacks or sanitized returnable plastic crates, so, it is recommended to use cushions at the bottom and on the sides in order to protect fruits from bruising.

Karagul and Gercekcioglu (2016) investigated the effects of different packaging types on Esme quince fruit. Polystyrene plates + polyvinyl chloride stretch film, packaging low-density polyethylene, and transparent polyamide were taken into consideration. The quince fruits were stored for 6 months and temperature was maintained at 0–2 °C, with relative humidity between 85 and 95% in the cold storage environment. The types of packaging material pose significant effects on flesh firmness during storage. For all packaging applications, a decrease in total soluble solids was observed and acidity was also increased due to the decrease in pH. Maximum reduction was seen in the application of polystyrene plates + polyvinyl chloride stretch film. The best results were found by the implementation of low-density polyethylene packaging, which induces the least changes in fruit quality. Also, least weight loss of about 0.14%was observed in low-density polyethylene packaging. All these changes resulted in delayed ripening and senescence, and enhanced shelf life, as well as maintaining fruit quality during storage.

Investigation on the application of potassium permanganate and polyethylene bag packaging was carried out on quince fruit. It was shown that interaction between potassium permanganate and polyethylene bags had a significant effect on the fruit peel color of quince during different storage periods at 20 °C. Maturity results in chlorophyll degradation and ethylene production occurs, while potassium permanganate absorbs the ethylene produced by fruits. Also, the storage of quince fruits in sealed polyethylene bags prevents the build-up of ethylene (Akbari and Ebrahimpour 2014a).

Modified Atmosphere Packaging

Modified atmosphere (MA) packaging differs from CA storage in that the atmospheric composition is not actively controlled. Most MA systems use semipermeable membranes to regulate gas exchange between the MA and the ambient air. It involves sealing of fresh produce into polymeric film packages so as to modify the O_2 and CO_2 levels within the package. In modified atmosphere packaging, it is always desirable to generate low O_2 and high CO_2 concentrations to influence the metabolism of the product. Low O_2 concentration and elevated CO_2 concentration primarily decreases the rate of respiration and senescence by reducing the synthesis of ethylene (Abeles et al. 1992). MA packaging is often a better approach for short-term storage of small quantities of produce than CA storage (Mannapperuma et al. 1989). Packaging isolates the products from the external environment, thus, reducing the exposure to contaminants and pathogens (Yehoshua et al. 2005). Chinese quince (*Pseudocydonia sinensis*) categorized as a low-respiration fruit can be best preserved at 0 °C for 152 days and at 10 °C for 50 days by using polyolefin film packages having high gas permeability. The films attain modified atmosphere of fairly lowered O_2 and a slight accumulation of CO_2 (8.1–10.2% O_2 and 1.3–2.4% CO_2). The atmospheric characteristics associated with free volume decrease of packages is attributed to the low respiratory quotient (RQ<0.7) of quince and high CO_2/O_2 permeability ratio (>4.6) of film. The higher fruit quality with this fruit packaging is sustained by its high ascorbic acid retention and small surface color change at the later storage period (160 days at 0 °C and 60 days at 10 °C) (An and Lee 2006).

Chemical Treatments for Shelf Life Extension

The use of 1-methylcyclopropene (1-MCP) has been evaluated on the postharvest fruit quality of quinces during storage. Quince fruits harvested were treated with 625 and 1250 ppb doses of 1-methylcyclopropene (SmartFresh™) for 24 h and were stored in plastic boxes at temperature 0–1 °C with relative humidity 85–90% for 2, 4, and 6 months, respectively. After these treatments and each storage period, some quality parameters like skin color, firmness, weight loss, total soluble solids, internal browning, and biochemical properties like titratable acidity were evaluated. The results showed positive effects on these properties by the application of 1-MCP during storage (Sakaldas et al. 2010). In another study, quince fruits were treated with 600 nL L^{-1} of 1-MCP and stored up to 151 days at 2 °C (no cover), 10 °C (in loosely closed polyethylene bags), or in a storage room with a gradual (within a month) drop in storage temperature from 20 to 2 °C (RH 80–90%). The control fruits were kept at ambient temperature (4–17 °C) and relative humidity (35–95%). The results showed that the fruits stored at 2 °C or treated with1-MCP remained greener as compared to those stored at higher temperatures. However, storage at

2 °C or treatment with 1-MCP did not show improvement in the flesh firmness of quince. Fruits kept at ambient conditions developed flesh browning and were the softest. Quinces stored at 2 °C or ambient conditions had lower values of soluble solid content and dry matter as compared to fruits stored at 10 °C in polyethylene bags. Thus, storing quince at 10 °C in polyethylene bags without 1-MCP treatment is recommended to keep their fruit quality acceptable for up to 106 days (Nanos et al. 2015).

The interaction between potassium permanganate and heat treatment on quince quality and storability was investigated. Quince fruits were treated with two levels of potassium permanganate, 2 and 4 g per kg of fruit weight, for 36–72 h at 38 °C and were packed in polyethylene bags. Bags were stored at 0 °C for 75 and 150 days at 85–90% relative humidity. The results showed that the application of 4 g/kg potassium permanganate and 36 h of heat treatment resulted in the lowest decrease in flesh firmness, change in skin color, and astringency. With respect to β-carotene content, total soluble solids, and astringency, significant differences were found between the two concentrations of 2 and 4 g/kg of potassium permanganate applications after 75 and 150 days of storage. After 150 days of storage, more satisfactory results were found in 4 g/kg potassium permanganate and 36 h heat treatment as compared to 2 g/kg potassium permanganate for 72 h in respect of astringency, flesh firmness, and skin color. However, the highest β-carotene content was found in quinces which received 2 g/kg of potassium permanganate treatment for 72 h. This is because potassium permanganate absorbs ethylene produced by the fruits. Also, a high amount of CO_2 and low level of O_2 in polyethylene bags resulted in low ethylene content, thus delaying maturity and β-carotene content (Klein and Lurie 1992; Akbari and Ebrahimpour 2014b).

Edible Coatings

Semperfresh is a sucrose ester-based fruit coating which is manufactured from approved food ingredients (sucrose, esters of fatty acids, sodium carboxymethyl cellulose, and mono-, diglycerides of fatty acids) and has been used for the packaging of quince. It is applied as a dip, spray, or drench method, which, after drying, forms an invisible, colorless, odorless, and tasteless coating. It gives an extended fresh appearance, better color retention, flavor preservation, and also delays softening and breakdown during storage, and reduces chilling damage and bruising. It has been found that the combination of Semperfresh and cold storage preserves the microbial quality of quinces by showing a considerable decrease in their log cycles. Semperfresh coating maintains an increased humidity, which provides a barrier against water loss from the quince surface. It also maintained high firmness values of quince due to the creation of a relatively dry environment, thus providing mechanical strength to external tissues of the fruit (Yurdugul 2005).

Postharvest Disorders

Several microbiological disorders/diseases can affect quinces, which can depart them from normal appearance, deprive their usefulness, and reduce their value. They are subjected to many diseases that can occur in the orchard and after harvest.

Black Rot

Black rot (*Physalospora obtusa*) is a disease of apples and is of minor importance for quinces. Infection of the fruit may usually occur due to insect injuries and other wounds or at the calyx end (Whetzel 1917). The major symptom of black rot is a firm brown or black spot on any part of the fruit. It can be controlled primarily by the elimination of deadwood by proper pruning. Prevention of insect and mechanical injuries and maintenance of temperature in storage (below 4.4 °C) and transit are also recommended (Rose et al. 1951).

Blue Mold Rot

Blue mold rot (*Penicillium expansum* Thoni) is one of the most common and most destructive rots found in pome fruits (apple, pear, quince, etc.) during transit, storage, and marketing. It occurs in all varieties of these fruits and is not restricted only to the orchard. This rot appears in the form of soft watery spots ranging from brown to pale straw in color. The decayed portions are separated sharply from the healthy tissues. Internally, the affected tissue appears watery and glassy, and can be easily scooped out from the healthy part. Blue mold rot can be controlled by careful handling, sanitation at packing houses as well as storage rooms, and prompt cooling to storage temperatures after harvesting. Sodium orthophenyl phenate is a commonly used fungicide for blue mold rot (Pierson et al. 1971).

Brown Rot

Monilinia fructigena brown rot is a common fruit rot of quince in Europe. Brown rot due to *M. laxa* is reported on fruits, blossoms, leaves, and twigs of quince. *Monilinia fructicola* can cause a severe fruit rot, which includes twig blight (Byrde and Willetts 2013). Like most other quince rots, brown rot can also be controlled by careful handling, rapid cooling, and prompt storage in cold rooms, as well as maintaining sanitary conditions after harvest (Walker 1957).

Conclusion

Being a climacteric fruit, quince will continue to ripen even after harvesting. Thus, during storage, green skin color, flesh firmness, acidity, and percentage dry matter will show a gradual decrease with ripening of the quince. Quince is susceptible to browning due to the presence of a high amount of phenolic compounds. Flesh browning percentage depends upon the type, amount, and activity of polyphenol oxidase, peroxidase, and phenylalanine ammonia-lyase. Pre- and postharvest factors, variety, inherent traits, amount of polyphenols at harvest time, storage temperature, storage period, transport, and mechanical damages during harvest are influential on the browning percentage. Quince is also susceptible to many in-field pathogenic attacks, which can be treated by the use of various chemical pesticides and fungicides.

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Postharvest Biology and Technology of Loquat

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Introduction

Loquat (Eriobotrya japonica Lindl.) belongs to the Rosaceae family and believed to have originated from China. It has been cultivated in Japan, northern India, the Mediterranean region, England, Madagascar and North, Central and South America. Loquat fruits are consumed mainly as fresh fruit, but recently they have been used to prepare various processed products like jam and jellies. Normally, flesh is the only part used in manufacturing of processed products (Koba et al. 2007).

Loquat fruit is round or oval in shape and weighs about 20–80 g. They occur in loose clusters. Ripe fruit has a soft and juicy flesh, and vary in color from white to deep orange (Ding et al. 1998). The fruit quality attributes relate to the ripening degree at harvest and the important attributes are skin color, flesh firmness, soluble solids content (TSS), acidity (TA) and TSS/TA ratio (Reid 2002). The harvesting time of loquat is based on visually assessed fruit skin color (Besada et al. 2010). The other parameters, such as TSS, TA and fruit firmness should be considered in order to ensure consumer satisfaction (Pinillos et al. 2011).

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Loquat fruit is highly perishable at ambient temperature due to flesh browning and microbial spoilage (Cao et al. 2008). A number of technologies have been evaluated for extending the shelf-life of loquat fruit and include cold storage, controlled atmosphere storage, modified atmosphere packaging, edible coatings, chemical and heat treatments.

Nutritional Composition

Loquat fruit has a great nutritional importance because of its special functional composition. Also, it has a high commercial importance due to increasing consumer demand. Ripe fruit are rich in proteins, minerals and carotenoids and other several essential nutrients. It also is a rich source of bioactive components such as flavonoids, triterpenic acids and carotenoids. These compounds are possess high radical scavenging activity against free radicals, thus making are very effective in inhibiting oxidation of human low-density lipoproteins. Fully ripe fruits contain higher amounts of carotenoids which give characteristic yellow to orange colour to the fully ripened fruit (Pareek et al. 2014).

The fruits are rich in A and B vitamins, mineral substances, salts, and sugar, making them important for nourishment during the low period of the fresh fruit season (Xu and Chen 2011). Hasegawa et al. (2010) analysed the chemical composition of five loquat cultivars of Brazil. The cultivar Mizumo having the highest total sugar concentration (11.48 g/100g) and the lowest concentration was observed in Centenaria (4.32 g/100g). The main sugar and organic acid present in loquat fruits is sucrose and malic acid, respectively. Ascorbic acid was found in small amounts (5.28-8.20 mg/100g). The total dietary fiber contents were almost the same in all cultivars (1.19-1.41g/100g). The major carotenoids reported were β-carotene and β-cryptoxanthin.

Maturity and Ripening

Fruit maturation involves various physicochemical changes that lead fruit to the mature stage. Fruit maturity can be assessed at harvest using different indexes such as skin colour, flesh firmness, soluble solids content, titratable acidity, soluble solids content / acidity ratio (Reid 2002). Sugar and acidity levels highly affect organoleptical quality of loquat fruit. Consumers prefer loquat with TSS higher than 10 °Brix (Kader 2009) and this TSS level is often considered commercial maturity (Gonzalez et al. 2003). A soluble solids content / acidity ratio ≥ 0.7 has been also proposed to take into account the acidity levels (Pinillos et al. 2007). However usually, loquat is harvested based on fruit skin colour.

The optimum quality of loquat fruit is obtained when it is harvested at the stage of high degree of ripening. However, commercially, it should be harvested before becoming fully ripe i.e., at the eating-ripe stage, when the skin has a yellowish-orange colour (Cuevas et al. 2003). The degree of fruit ripening significantly affects the incidence of bruising. The bruised area and volume increases significantly with the degree of ripening.

Loquat fruits are usually harvested before reaching full ripening stage because of the huge importance of fruit earliness in loquat price and commercialization. Another reason for premature harvest of loquat fruit is the high susceptibility of mature fruit to mechanical damage during harvesting and postharvest handling. Since it is a non-climacteric fruit, premature harvest results in fruits that have a high acid content and unpleasant taste to consumers. The 'Algerie' loquat fruits were picked at four different stages of maturation in order to determine their susceptibility to mechanical damage, fruit quality and consumer acceptance with a view to proposing the best fruit maturation stage for harvesting. The results revealed that the maturation stage at harvest strongly affects bruising incidence due to a decrease in fruit firmness during ripening. The fruit quality and consumers acceptance was also highly dependent on maturity stage at harvesting time. The fruits with a minimum value of TSS (10 °Brix) and a TSS/TA ratio close to 1.0 (Brix/g malic acid L-1) at harvesting time showed better eating quality and consumer acceptability (Cañete et al. 2015).

Loquat falls into yellow and white-fleshed cultivars. Where the yellow-fleshed cultivars appear orange, and have dense flesh, thick peel and good resistance to stress during storage and transportation, while the white-fleshed counterparts are milky- or light-yellow fleshed, tender, juicy and delicious, widely received by consumers for its pleasant flavor and taste. Carbohydrate is an important index for fruit quality. Loquat fruit mainly accumulate fructose and glucose at maturation stage, where the contents of fructose and glucose are higher than yellow-fleshed cultivars respectively; but the sucrose and sorbitol contents are very low (Chen et al. 2010).

Cold Storage

Low-temperature storage is widely used to increase the shelf life, reduce decay and maintain quality of loquat fruit. The ripe fruits showed higher storage capacity compared with fruits harvested at mid-ripe or over-ripe stage (Ding et al. 2006). However, cold storage results in a series of chilling injury symptoms such as flesh leatheriness and lignification, leading to the degradation of loquat fruit quality during storage (Cao et al. 2010a, b).

The optimum storage temperature for loquat fruit depends on the cultivar susceptibility to chilling injury. The minimum temperature to prevent chilling injury ranges from 0 to 10 ºC. The optimum temperature for 'Jiefangzhong', 'Zhaozhong' and 'Wuxing' cultivars is 6-8 ºC, 8-10 ºC and 1 ºC, respectively, for 30 days (Tian et al. 2007). Ding et al. (2006) reported that fresh fruit quality of 'Mogi' loquat could be

maintained at 1 or 5 ºC for 30 days of storage. The shelf life was 15 days at 10 ºC and 10 days at 20 ºC owing to high respiration rates of 40.0 and 15.3 mL CO_2 kg^{-1} h^{-1}, respectively. The high respiration rates produced high CO_2 levels in the core or the pulp tissue, resulting in the breakdown in fruits stored at higher temperatures. Malic acid concentration decreased with the decrease in storage temperature of the loquat fruit.

Firmness of loquat fruit changes considerably during the postharvest storage. Temperature has a significant effect on fruit firmness and it increases in the fruits kept at low temperatures. Zheng et al. (2000a) reported an increase in firmness and lignin content in loquat fruit ('Dahongpao' and 'Jiefangzhong') after 3 weeks of storage at 1ºC. These fruits showed stuck peel, leathery and juiceless pulp. However, the fruits stored at 12 ºC showed little change in firmness and lignin.

Two loquat cultivars 'Morphitiki' and 'Karantoki' under different storage regimes were studied by Goulas et al. (2014). The fruits were harvested at commercial maturity stage and stored at room temperature (20 °C) or at cold storage (4 °C). Firmness was not affected during storage, the cell wall exhibited extensive remodelling. Greater changes were observed in the pectin backbones than in polyuronide side chains and cross-linking glycans. Cold storage inhibited the cell wall disassembly in 'Karantoki' but not in 'Morphitiki', suggesting that the cultivars may differ in their susceptibility to chilling-related wall disorders.

Cai et al. (2006) reported that the firmness of loquat ('Luoyanqing') fruit flesh increased during stored at 20 ºC. This increase in fruit firmness was positively correlated with increase in lignin content and caused by the enhanced activities of related enzymes such as phenylalanine ammonia lyase, cinnamyl alcohol dehydrogenase and peroxidase. According to (Amaros et al. 2008) the firmness of loquat increased significantly during the first four weeks of storage in all treatments after which no significant difference was observed till the end of storage.

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is a technique used to increase the shelf-life of fresh fruits. In this technique the gas composition surrounding the fruit inside the package is changed to another desired gas composition. MAP is used with different types of fruits, and the gas mixture to be filled in the package depends on the type of fruit, packaging materials and storage temperature. Since fruits are respiring products and thus their interaction with the packaging material is very important. If the permeability (for O_2 and CO_2) of the packaging film is adapted to the product respiration, an equilibrium modified atmosphere will establish in the package and the shelf-life of the product will increase.

Ding et al. (2002) investigated the effects of MAP on the storage life of loquat fruit cv. Mogi and reported that fruit stored under MAP showed minimum water loss (0.9-1.5%), while as perforated polyethylene packaged fruit showed higher water loss (8.9%) after storage for 60 days at 5 °C. MAP significantly retained loquat organic acid levels, although total sugars were not significantly affected.

Lower gas permeance MAP increased fruit physiological disorders, including internal browning. Fruit stored at high temperature (20 °C) sustained severe decay, and MAP increased the incidence of decay. Bagging loquats with 20 m thickness polyethylene at 5 °C resulted in an in-bag atmosphere of approximately 4 kPa O_2 with 5 kPa CO_2, and in the highest scores for appearance and chemical compounds. Loquat fruit packaged under these atmosphere conditions could be stored for 2 months at 5 °C with a higher quality and minimal risk of disorder development.

Loquat fruits cv. Algerie were stored in MAP using five types of microperforated polypropylene films during 2, 4, and 6 weeks at 2 °C and for a subsequent period of 4 days at 20 °C shelf life out of the bags. Loquat fruits stored without packaging and in normal air served as control. The atmosphere composition at the steady state depended on the film permeability, ranging from 1.2 to 8.5 kPa for CO_2 and from 19.5 to 13 kPa for O_2 as film permeability decreased. Weight loss was drastically reduced by MAP conditions. Softening, colour evolution, and decreases in sugars and organic acids were delayed, these effects also being evident after the shelf life period. Scores for visual aspect and facility of peeling were also higher for loquat stored in MAP than for controls. Results revealed that the most suitable atmosphere for loquat storage was found to be around 2-4 and 16–18 kPa for CO_2 and O_2, respectively. In addition, the storage period for optimum loquat quality maintenance was established as 2 weeks of cold storage plus shelf life for control fruits, while under MAP conditions, storage periods could be extended up to 6 weeks plus shelf life (Amaros et al. 2008).

The influence of MAP on the sensory and quality attributes in loquats cv. Jiefangzhong stored at 2~4°C was investigated in order to prolong shelf life in this study. The plastic film was used: perforated low density polyethylene (Control) and low density polyethylene. The modified atmosphere reached the steady state was (4.8 ± 0.67)% CO_2 and (11.5 ± 0.85)% O_2. Changes in respiratory rate, total soluble solids, titratable acidity, pH value, flesh firmness, vitamin C, weight loss and quality were recorded periodically for comparing the effects of the applied conditions. It is showed that the combination of a MAP and low temperature significantly reduced the respiratory rate of loquat. The quality attributes of MAP fruit were good, and MAP induced minimum differences in weight loss, firmness, vitamin C, total soluble solids, titratable acidity and total soluble solids /titratable acidity ratio during storage compared with control fruit, and also maintained the sensory quality at harvest of loquats at the end of storage and shelf life period. Therefore, it is feasible that MAP with a low density polyethylene film should be recommended for storing loquats (Fahe et al. 2003).

Controlled Atmosphere Storage

The effects of various storage conditions on fruit quality, respiratory rate and ethylene production in loquat were studied by Qin et al. (1994). Temperature treatment (3±1°C) could prolong storage periods evidently. Especially, controlled atmosphere storage at low temperature could greatly delay the losses of soluble sugar, soluble

solid content, titratable acid and reduced ascorbic acid. Loquat fruits could be stored over 40 days. This is related to the inhibition of respiration and ethylene production by low temperature and low O_2.

Loquat fruit in controlled atmosphere with 10 kPa O_2 + 1 kPa CO_2 could be stored for 50 days at 1°C with normal flavor and low decay incidence. Controlled atmosphere containing 12 kPa CO_2 with either air or 2 kPa O_2 was reported to induce severe internal browning in loquat fruit (Ding et al. 2002). Short-term high-O_2 (70 kPa) treatment for 24 h followed by storage in controlled atmospheres with 10% O_2 + 1% CO_2 at 1 °C had little effect on fruit flavor but stimulated ethanol accumulation in loquat fruit and reduced activities of endo-polygalacturonase and exo- polygalacturonase. Controlled atmospheres conditions (10% O_2 + 1% CO_2 at 1 °C) also reduced polyphenoloxidase activity and increased peroxidase activity but had little effect on phenylalanine ammonium-lyase activity, leading to reduced flesh browning. Thus, control of tissue browning in loquat fruit through inhibition of oxidases and mitigation of oxidative stress during low temperature storage is important and advantageous being associated with the controlled atmospheres storage of loquat fruit (Ding et al. 2006).

Fruits of loquat cv. Jiefangzhong were stored in polyethylene bags of 0.04 mm thickness and containing over 90% O_2 at 1°C for 35 days. Results showed that the respiration rate of control fruits gradually decreased during storage, but the respiration rate of fruits treated with 90% O_2 decreased more markedly. High O_2 treatment noticeably inhibited polyphenol oxidase activity, and browning of pulp lightened during the course of storage. Total soluble solid contents and titratable acidity decreased at a slow rate in fruits treated with high O_2. After storage for 35 days, the flavour of treated fruits was better than that of control fruits (Zheng et al. 2000).

Chemical Treatments

1-Methylcyclopropene

1-methylcyclopropene (1-MCP) is an ethylene inhibitor and several reports have shown that treatment with 1-MCP had positive effects on postharvest quality and shelf life of loquat fruit. Cai et al. (2006) reported that exposure to 1-MCP at 5 mL L^{-1} significantly decreased internal browning and delayed the increase in firmness of 'Luoyangqing' fruit cultivar. These findings were associated with lower lipoxygenase and polyphenol oxidase activities and reduced oxidation of polyphenols in the 1- MCP-treated fruits. Cao et al. (2010a) reported that exposure to 1-MCP at 0.05 mL L^{-1} significantly reduced chilling injury damage in loquat fruits cv. Fuyang, reduced malondialdehyde accumulation, and inhibited increases in electrolyte leakage rates and in accumulation of superoxide and hydrogen peroxide radicals during 35 days of cold storage at 1°C. These workers also observed that exposure to 1-MCP increased flesh firmness, and enhanced solubilization of pectins in the cell walls. Similar results regarding the effects of 1-MCP in reducing internal browning, and increase in firmness and decrease in

extractable juice were reported by Zheng et al. (2005). Liguori et al. (2014) reported that exposure to 1-MCP at 0.5–1 mL L^{-1} significantly inhibited the decline in juice total soluble solids and titratable acidity levels in 'Biqizhong' and 'Claudia' loquat varieties, respectively.

1-MCP treatment significantly alleviated chilling injury in 'Fuyang' loquat fruit. This treatment obviously inhibited the accumulation of malondialdehyde, superoxide radicals and hydrogen peroxide and the increase in electrolyte leakage. 1-MCP-treated fruit showed significantly higher catalase activity and lower lipoxygenase and phospholipase C activities than control during storage (Cao et al. 2009).

Methyl Jasmonate

The effect of methyl jasmonate (MeJA) on loquat fruit was investigated by Cao et al. (2010b). This treatment effectively decreased the chilling injury symptoms, delayed the increase in lignin, alcohol insoluble residues, hemicellulose and cellulose content. The treated fruits showed significantly lower activities of phenylalanine ammonia lyase, peroxidase, polyphenol oxidase and higher polygalacturonase activity than the control during storage. The reduction in chilling injury by MeJA may be due to reduced lignin accumulation and increased cell wall polysaccharides solubilisation.

Jin et al. (2014)studied the effects of a combined treatment of hot air and MeJA (16 μmol L^{-1}) on chilling injury, fruit quality, and physiological changes in loquat fruit stored at 1 °C and reported that the treatment with hot air or MeJA alone significantly alleviated chilling injury in loquat fruit compared with the control. However, the combined treatment showed the lowest level of chilling injury symptoms and the fruit was of the highest quality. The activities of antioxidant enzymes such as superoxide dismutase, ascorbate peroxidase, and catalase were enhanced by the combination of hot air and MeJA. The results suggested that the enhanced chilling tolerance by combination of hot air and MeJA treatment in loquat fruit was related to the induction of antioxidant enzymes and the inhibition of lignin biosynthesis. The MeJA treatment can significantly delay anthracnose rot and flesh leatheriness development in loquat fruit during storage at ambient temperature and thus may be used commercially to increase the shelf life of loquat fruit (Cao et al. 2009, 2014).

Calcium Chloride

Calcium is an essential element for plant growth and development and also has a potential role in maintaining postharvest quality of fruit and vegetables by maintaining the structure of cell wall components. The presence of calcium ions increases the cohesion of cell-walls (Demarty et al. 1984). It is also involved in decreasing the

rate of senescence and fruit ripening. Babu et al. (2015) studied the effectiveness of different calcium treatments on the post-harvest physiology and quality of loquat fruit. Freshly harvested loquat fruit was treated with different concentrations of calcium chloride (1%, 2% and 3%), stored at 4 °C, RH 85-90%. Results showed significant retention of firmness and ascorbic acid content in samples dipped in 3% calcium chloride. Total soluble solids content was inversely correlated with acidity and throughout the 24-day storage period was significantly lower in samples treated with 3% calcium chloride than the untreated samples.

Akhtar et al. (2010) studied the effect of calcium chloride (1%, 2% and 3%) treatments on postharvest quality and storage behavior of "Surkh" cultivar of loquat. The results revealed that 1% calcium chloride did not affect quality parameters of the fruit compared to control treatment, whereas, 2 and 3% calcium chloride retained maximum firmness, total soluble solids, ascorbic acid content, reduced browning index, relative electrical conductivity and weight loss up to 4-5 weeks.

Ethanol

Ethanol treatment of fruits has been reported to control postharvest diseases and decay. Ethanol inhibited the growth of gray mold decay and increased the shelf-life of fruits (Karabulut et al. 2004; Lichter et al. 2002 Lurie et al. 2006; Margosan et al.1997; Wang et al. 2011).

Wang et al. (2015)studied the effect of ethanol treatment on disease resistance against anthracnose rot in loquat fruit and reported that the treatment with ethanol at 300 μL/L^{-1} significantly inhibited the anthracnose rot caused by *Colletotrichum acutatum* and maintained the overall quality. This treatment decreased activities of catalase and ascorbate peroxidase while increased superoxide dismutase activity in *C. acutatum* inoculated loquat fruit, thus resulting in a higher level of H_2O_2, which might serve as a crucial role to activate disease resistance. Meanwhile, the activities of defense-related enzymes including phenylalanine ammonia-lyase, peroxidase, polyphenol oxidase, chitinase and 1,3-glucanase were significantly enhanced by the ethanol. Also, in vitro ethanol treatment at a concentration of 300 μL/L^{-1} showed significant antifungal activity against spore germination and mycelial growth of *C. acutatum*.

Edible Coatings

Chitosan coating has been widely used to increase the shelf life of fruits. The effect of chitosan coating on postharvest life of loquat was investigated by Ghasemnezhad et al. (2011). Fruits were treated with 0, 0.25, 0.5, 0.75 and 1% chitosan solutions and stored at 7 °C and 88±2% relative humidity for 28 days. Chitosan coating significantly reduced weight loss and decreased browning compared with the control. The results revealed that the most effective chitosan concentration was 0.75%.

The effect of chitosan coating (1%) on the quality of three loquat cultivars (Algerie, Nespolone Rosso di Trabia and Golden Nugget) was studied by Petriccione et al. (2015). Chitosan treatment effectively reducedfruit weight loss and delayed changes in the soluble solids concentration, titratable acidity and skin colour during 21 days of cold storage, depending on the cultivar. Also, the chitosan treatment resulted in decrease in losses of the total polyphenol, flavonoid, carotenoid, ascorbic acid content and the antioxidant capacity.

Song et al. (2016) studied the effect of chitosan/nano-silica coating on chilling tolerance in white-flesh loquat fruit (cv Baiyu) stored at 5 °C for 40 days. The chitosan/nano-silica treatment reduced the internal browning and weight loss as compared to untreated fruits. It also inhibited the decrease of total soluble solids and titratable acidity and lowered the levels of malondialdehyde and membrane permeability. The results indicated that the use of chitosan/nanosilica coating was effective in enhancing chilling tolerance and providing a longer storage life with acceptable external and internal quality in loquat fruit.

Heat Treatment

The development of chilling injury in loquat fruits limits the keeping quality during long period of cold storage which emphasis the use of new methods to maintain the quality and increase the shelf life of loquat fruit. The effect of hot water dipping (45 °C for 10 min) combined with glycine betaine (10 mmol L^{-1}) treatment on chilling injury, fruit quality and physiological changes in loquat fruit stored at 1 °C were investigated by Zhang et al. (2016). The results showed that treatment with hot water dipping or glycine betaine alone significantly alleviated chilling injury in loquat fruit compared with the control. The combined treatment of hot water dipping and glycine betaine was more effective in reducing chilling injury and maintaining quality parameters than hot water dipping or glycine betaine alone. Also, the combined treatment significantly reduced ion leakage, and malondialdehyde content in loquat fruit. The activities of antioxidant enzymes including superoxide dismutase, catalase and ascorbate peroxidise were higher in the combined treatment than those in the control. The results revealed that the combined treatment increased chilling tolerance in loquat fruit by inducing antioxidant enzymes activities and proline or λ-aminobutyric acid metabolism (Zhang et al. 2016).

Rui et al. (2010) studied the effect of heat treatment (38 °C) on internal browning and membrane fatty acid composition of the loquat cv. Jiefangzhong during storage at 1 °C for 35 days. This treatment decreased the internal browning and inhibited the increase of internal browning index in loquat fruit. Heat treatment maintained lower levels of electrolyte leakage and malondialdehyde content, and inhibited the increase in phospholipase D and lipoxygenase activities compared with the control fruit. The results suggest that the reduction of internal browning in chilled loquat fruit by heat treatment might be due to maintenance of membrane integrity and higher unsaturated/saturated fatty acid ratio.

Liu et al. (2010) studied the effect of heat treatment (hot air at 38°C for 36 h) and Pichia guilliermondii, either alone or in combination, against anthracnose rot in loquat fruit and reported that the combined treatment significantly reduced natural decay, disease incidence and lesion diameter in artificially inoculated fruit.

Physiological Disorders

Chilling Injury

Chilling injury is a physiological disorder that occurs in loquat fruit during low temperature storage, which limits its long-term storage and long-distance transportation. The major symptoms of chilling injury in loquat fruit are internal browning, leathery, juiceless flesh, and adhesion of peel to the pulp (Cai et al. 2006). The occurrence of chilling injury was related to the abnormal metabolism of cell wall substances since the activities of pectin methylesterase and polygalacturonase declined while protopectin, lignin and fiber contents increased (Zheng et al. 2000a). Chilling injury also changed the levels of spermine, spermidine, and putrescine in flesh of fruit. The accumulation of putrescine could be a cause of the injury and the increase in spermidine level could be due to chilling stress (Zheng et al. 2000b). Also, the development of chilling injury could be the due to oxidative stress which may induce peroxidation and breakdown of unsaturated fatty acids in membrane lipids (Lyons 1973). Various treatments including modified atmosphere packaging, 1-MCP and methyl jasmonate treatment have been exploited to reduced the chilling injury and thus increase the shelf life of fruit after harvest.

Flesh Browning

Flesh browning is a serious problem which limits the postharvest life and processing of loquat fruit. During storage, flesh browning occurs from the core area and is accompanied by lignification of the flesh tissue. Polyphenol oxidase, which acts upon polyphenolic compounds, is the main enzyme responsible for the enzymatic browning reactions. The main phenolic compounds in ripe loquat fruit are chlorogenic acid, neochlorogenic acid, hydroxybenzoic acid and feruoylquinic acid. Several compounds such as sulfites, ascorbic acid and cysteine have been reported to prevent flesh browning in loquat fruit (Ding et al. 2002).

Purple Spot

Loquat fruit is sensitive to purple spot, a physiological disorder that affects the crop worldwide. This disorder appears at fruit color break and mainly affects early cultivars (Reig et al. 2007). The purple spot develops by change in the water relationship

between the flesh and the rind. Purple spot is characterized by an extensive area of slightly depressed and irregularly shaped surface with purple color that affects up to 30% of the exposed surface of the fruit (Caballero 1993).

Purple spot in loquat fruits may be reduced by the application of calcium nitrate, calcium chloride, ammonium nitrate and potassium nitrate before fruit colour break. These chemicals reduce the water potential in the epidermal tissue and allow it to retain more water (Gariglio et al. 2005).

Conclusion

Loquat fruit is round or oval in shape weighing about 20–80 g and occur in loose clusters. The fruit flesh is soft and juicy, varying in color from white to deep orange. These fruits are consumed mainly as fresh fruit, but recently they have been used to prepare various processed products. Loquat fruit is highly perishable at ambient temperature due to flesh browning and microbial spoilage. A number of technologies have been evaluated for extending the shelf-life of loquat fruit and include cold storage, controlled atmosphere storage, modified atmosphere packaging, edible coatings and heat treatments. In addition, various chemical treatments including 1-methylcyclopropene, methyl jasmonate, calcium chloride and ethanol are being employed to enhance the shelf life of loquat fruit.

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Postharvest Biology and Technology of Kiwifruit

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Introduction

Kiwifruit (*Actinidia deliciosa*) is a hexaploid species and belongs to the family Actinidiaceae and order Ericales (Huang et al. 2013). It is believed to have originated in China and the major center of diversity of the genus *Actinidia* is the hilly region of southwestern China (Litz 2005). It is also known as 'China's miracle fruit', 'the horticultural wonder of New Zealand', and 'Chinese gooseberry'. It was introduced to New Zealand, from where it was popularized throughout the world. Kiwifruit is a functionally dioecious, perennial, deciduous climbing vine fruit crop, which bears dull brown berry type fruit similar to sapota, with small hairs on its surface and its flesh is light green in color with small, soft, dark seeds. The global production of kiwifruit was over 1.4 million tons in 2012, and Italy leads in production, with 384,000 tons over an area of 24,800 ha (FAOSTAT 2014). The world production of kiwifruit is dominated by one cultivar, i.e., Hayward, which was chosen by a nurseryman in 1930 from New Zealand (Ferguson 1984) because of its size, taste, longer storage, high antioxidant capacity, and vitamin C content (Testolin and Ferguson 2009).

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Kiwifruit is an economically important fruit crop and is highly appreciated for its high concentrations of bioactive compounds (i.e., antioxidants) that are directly correlated to its capability to endure extended cold storage (Tavarini et al. 2008). At low temperature (0 °C), kiwifruit has a unique climacteric behavior, as it does not produce substantial ethylene until softening (Feng et al. 2002; Atkinson et al. 2011). However, kiwifruit produces little ethylene (0.01 μL kg^{-1} h^{-1}) at harvest (Burdon and Lallu 2011). Kiwifruit produces autocatalytic ethylene during ripening and, therefore, is considered climacteric (Sfakiotakis et al. 1997; Antunes 2007; Chiaramonti and Barboni 2010). After harvest, it does not exhibit any change for about a week at room temperature (Chattopadhayay 2008). This led to an extended postharvest life in cold storage at 0 °C. Exogenous treatment of ethylene or propylene initiates interior autocatalytic ethylene response and rapid flesh softening (Sfakiotakis et al. 1997). Even, naturally, a few weeks after harvest, there is a quick increase in its respiration rate, which elicits the ripening process; thereby, it deteriorates at a faster rate and limits its shelf life to only about 3–4 days after ripening (Sharma et al. 2012). The critical factor accountable for deteriorating the shelf life and quality of harvested kiwifruits is the rapid softening due to loss of moisture as well as texture and fruit decay either during cold and controlled atmosphere storage or in the commercial market place (Crisosto et al. 2000; Park and Kim 2002; Fattahi et al. 2010). Kiwi fruits are extremely ethylene sensitive. The minimum concentration of ethylene that induces premature ripening and flesh softening is 0.03 ppm. Arpaia et al. (1986) reported that fruit softens rapidly even under cold storage condition at 0 °C temperature with the presence of minute ethylene molecules (0 or 1 μL/L) in the surrounding air. Fruit softening can also be caused by numerous factors during handling, storage, or transportation, such as endogenous physiological, biochemical, and metabolic changes that take place within fruit at postharvest conditions. The preharvest damage can be caused by insects, diseases, birds and/or hail, chemical injuries, and a range of blemishes (such as scars, scabs, abrasions, and staining), which, if unnoticed during processing, can cause loss during postharvest storage. In New Zealand, the industry has faced an average loss of 11.6% for green kiwifruit and 10.6% for the gold variety (NZPA 2007).

The above discussed factors are the major challenges for postharvest scientists. These factors that affect postharvest decay/deterioration rate and quality are in urgent need to be understood and manipulated (Hewett et al. 1999). Thus, prior to developing any postharvest technologies to reduce postharvest losses with longer shelf life, it is required to learn about and understand the physiological and environmental factors associated with postharvest fruit decay, and this facilitates in developing various postharvest technologies, methods, or treatments to delay senescence, maintain best promising quality, and extending the postharvest life of the fruits (Kusano et al. 2007; Schotsmans et al. 2009). So, with this concern, there is a need for developing treatments or procedures which reduce its softening by delaying ripening or interfering with physiological and biochemical changes, especially enzymatic activities, which would be very useful for extending the availability of kiwifruits on the market. Cool storage is widely used to reduce the respiration rate and extend the shelf life of kiwifruit. This slow down of the metabolism must be prior to transportation or storage (Zhang et al. 2003). There are many opportunities

to reduce quality deterioration associated with biological factors by selecting genotypes that have lower respiration and ethylene production rates, less sensitivity to ethylene, slower softening rate, improved flavor quality, enhanced nutritional quality, reduced browning potential, decreased susceptibility to chilling injury, and/or increased resistance to postharvest decay-causing pathogens.

Nutrient Composition and Health Value of Kiwifruit

Kiwifruit is a rich basket of phytonutrients and bioactive compounds, including carbohydrates, vitamins A, C, E, and K, folate, and polyphenols (Iwasawa et al. 2011) (Table 1). It is widely known for its extremely nutritious and health benefit

Table 1 Nutritional composition in two commercially grown cultivars of kiwifruit

Nutrients	*Actinidia deliciosa* 'Hayward'	*Actinidia chinensis* 'Hort16A'
Moisture (g)	83.07	83.22
Protein (g)	1.14	1.23
Total lipids (g)	0.52	0.56
Ash content (g)	0.61	0.76
Total dietary fiber (g)	3.0	2.0
Total sugars (g)	8.99	10.98
Energy (kcal)	61	60
Minerals		
Ca (mg)	34	20
Fe (mg)	0.31	0.29
Mg (mg)	17	14
P (mg)	34	29
K (mg)	312	316
Na (mg)	3	3
Zn (mg)	0.14	0.10
Cu (mg)	0.13	0.14
Vitamins and others		
Ascorbic acid (mg)	92.7	105.4
Vitamin A (IU)	87	72
Thiamin (mg)	0.027	0.024
Riboflavin (mg)	0.025	0.046
Niacin (mg)	0.341	0.28
Pantothenic acid (mg)	0.183	0.5
Pyridoxine (mg)	0.063	0.057
Total folate (μg)	25	34
Beta carotene (μg)	52	43

Source: USDA National Nutrient Database Release 27 (2014) Statistics report 09148 Kiwifruit, green, raw

properties, along with low caloric value (Drummond 2013). Fruit juices also have strong potential to cure cardiovascular and cancerous diseases. Fresh fruits also show anti-inflammatory effects. Recently, it has been seen that doctors are also recommending kiwifruit consumption for patients suffering from dengue in India, owing to its medicinal benefits in increasing platelets in blood. However, the levels of nutrients and phytochemicals vary according to the genotypes of kiwifruit and are affected by different pre- and postharvest factors. Fruits contain a fair amount of ascorbic acid, ranging from 80 to 300 mg 100 g^{-1} (Ferguson and Huang 2007), which is about 1–2 times more than orange, 10 times as much as banana, or up to 15 times as much as apple (Vissers et al. 2013). It is also a huge source of several mineral elements like Ca, K, Fe, and Mg, as well as amino acids and dietary fiber. It also contains significant amounts of pigments, including chlorophylls, carotenoids, polyphenols, and flavonoids (Atkinson and MacRae 2007). As a good source of antioxidants, they may protect the body from metabolic internal oxidative injury (Stonehouse et al. 2012). The most convincing evidence is probably that kiwifruit consumption can improve gastrointestinal function, especially in those individuals with constipation (Singletary 2012). Another very important property is anticarcinogenic activity, as frequent consumption of juice may inhibit cancerous cell development and can protect from different types of cancers, such as stomach, lung, and liver cancers, as well as protect from cardiovascular diseases (Qian and Yu 1992). Some researchers also reported that kiwifruit may have some adverse effects on human health, such as stomach pains, itching and bulging of lips, a disease called ‘dermatitis’ owing to its composition of a proteolytic enzyme called ‘actinidin’, and the presence of calcium oxalate crystals (Zina and Bundino 1983; Perera and Hallett 1991).

Postharvest Biology of Kiwifruit

Fruit Morphology

Botanically, the fruit type of kiwi is a berry that contains a large number of small seeds which are embedded in the flesh of fruits either singly or in groups of 3–5 (Ferguson 1984) (Fig. 1). The structural regions of the fruit consist of one outer surface region called epicarp, inner pericarp, and central core, which is known as columella. The inner pericarp has multiple locules that embed the seeds. The size of the fruits ranges from 100 to 200 g of commercial varieties of two species, *Actinidia deliciosa* and *Actinidia chinensis*. Fruits of these commercial cultivars are subglobose to cylindrical in shape, with soft hairs on the surface. These hairs vary in color from brown to green. The internal flesh color is also green in *Actinidia deliciosa* and slightly yellow in *Actinidia chinensis*.

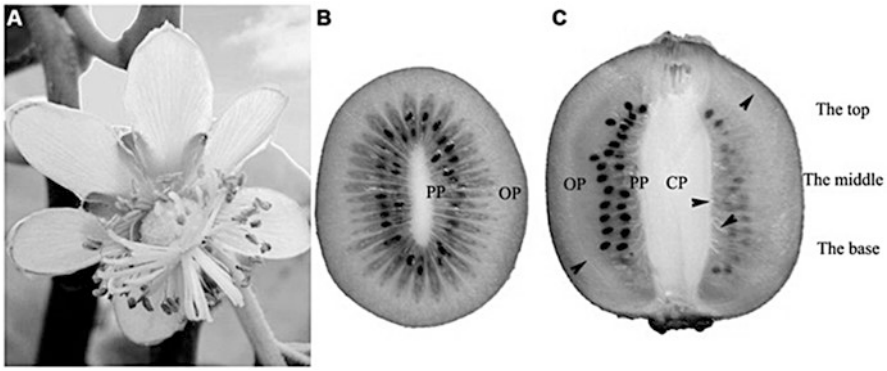

Fig. 1 Female flower and fruits of *Actinidia deliciosa* var. *deliciosa* 'Qinmei.' (**a**) A female flower, showing syncarpous pistil constituted of many carpels. (**b**) Mid-cross-section of fruit, showing many carpels around the axile placenta. (**c**) Longitudinal mid-section of fruit. Note the major vascular bundles (*arrowheads*) of fruit. *CP* central placenta, *PP* peripheral placenta, *OP* outer pericarp. Source: Guo et al. (2013)

Fruit Growth, Maturation, and Ripening

Fruit growth involves phloem and xylem stream, transpiration from the skin of the fruit, and inner biological processes such as cell division, differentiation, metabolism, and catabolism. The ultimate fruit size and composition are a result of the coupled import of water and carbon during growth (Hall et al. 2013). Unlike other deciduous fruits, kiwifruit have a lengthy growth period that finishes within 24 weeks from anthesis until harvest, though over 50% of the increase in fruit weight occurs during the first 2 months after anthesis, with a much slower increase thereafter (Beever and Hopkirk 1990). Previous studies reported that kiwifruit has a triple sigmoid growth curve in the growth volume of fruit (Pratt and Reid 1974; Scienza et al. 1983), whereas Hopping (1976) established a double sigmoid growth curve. Besides, later, some scientists observed a simple sigmoid curve (Beever and Hopkirk 1990; Gallego and Zarra 1997). The leaf area shows a linear relationship with the final fruit weight at a rate of 5–6 g per 100 cm^2 leaf over the range 300–700 cm^2 per fruit (Snelgar and Thorp 1988; Lai et al. 1989). Similarly, the number of seeds per fruit also affects fruit weight. It is reported that the fruit weight of kiwifruit reduced by 3.3 g when the seed number reduced from 1119 to 1040 (Pyke and Alspach 1986). Leaves are important to obtain consistent red flesh pigmentation in *Actinidia chinensis* fruit (Nardozza et al. 2015). Mature fruit sizes from early flowers are bigger compared to delayed flowering fruits at harvest, which is due to the significantly higher cell number in the outer pericarp in the fruit of the earliest flowering type over fruits of the late flowering type (Patterson et al. 1999; Cruz-Castillo et al. 2002). The single fruit weight of kiwi is completely linked to the fruit longitudinal diameter, fruit width, fruit thickness, and leaf shape index, and is

significantly and positively related to leaf length (Fanglun et al. 2016). The dry weight accumulation is directly related with the five-fold drop in water uptake rates in the kiwifruit (Hall et al. 2004). Cellulose is the chief wall polysaccharide, with galactose and uronics, the main non-cellulosic sugars. Much solubilization of cell wall pectic polysaccharides is detected. While wall galactose solubilization starts 90 days after anthesis, polyuronide degradation starts 30 days before the harvest date. Parallel to these processes, a linear increase in water-soluble polysaccharides was detected (Gallego and Zarra 1997).

Fruit ripening is a complex, genetically programmed senescence process, which initiates with softening and change in skin color. Softening of many fruits during ripening is often credited to a loss of cell wall integrity, a process involving several chemical changes to the component polysaccharides of the cell wall (Redgwell and Fry 1993). Kiwifruit softening is caused by cell wall dissolution, which involves pectin solubilization, galactose loss, and marked cell wall swelling. Almost all of these changes occurred during the first phase of fruit softening, when the fruit firmness decreased from −9.0 to −1.0 kg-force (kgf), before attaining eating ripeness. Mature kiwifruits exhibit a rapid drop in firmness after harvest until the fruit attains a firmness of ≈25 N (2.5 kgf) (Lallu et al. 1989). Unlike other fruit crops, there is only little change of chloroplasts into chromoplasts with a linked loss of chlorophyll and improved carotenoids content in kiwifruits. The chlorophylls level reduces gradually (Ben-Arie et al. 1982), as does the total carotenoids content. Changes in the color and appearance of the fruit flesh during ripening are mainly owing to changes in starch content (Matsumoto et al. 1983). On prolonged storage, kiwifruit steadily lose color and this has been associated with a loss of chlorophyll (Possingham et al. 1980; Ben-Arie et al. 1982). Most of the carbohydrate (stored as starch) becomes hydrolyzed and the soluble solids fraction increases rapidly as the kiwifruit grows (Richardson et al. 1997). The insoluble starch is converted into glucose (2–6%), fructose (1.5–8%), and sucrose (2%), which is another major characteristic of kiwifruit ripening (Beever and Hopkirk 1990).

Harvesting

Harvesting of kiwifruit at improper stages leads to quality reduction and less consumer demand. So, it is necessary to harvest fruits at the optimum maturity stage. A reliable maturity index should be developed to judge the fruit maturity and harvesting, as it is a major feature that is lacking in the kiwifruit production technology. Many researchers carried out work on this aspect. In New Zealand, commercial growers use the soluble solids content (SSC) as a maturity index for consumer acceptability and export purposes, especially for the 'Hayward' cultivar. At the time of harvesting, the optimum concentration of soluble solids of 6.2°Brix was used for export and it was first adopted in 1980 by kiwi growers (Burdon 2015). After ripening, this concentration should be 14%. This concentration of soluble solids has been

Table 2 Effects of cold storage on the physicochemical properties of kiwifruits

S. no.	Physicochemical parameters	Remarks	References
1	Flesh firmness	Significantly decreased	Tavarini et al. (2008)
2	Soluble solids content (SSC)	A steady increase observed at 0 °C	Manolopoulou and Papadopoulou (1998)
		Initially increased and then remained almost constant	Antunes and Sfakiotakis (2002)
		Significantly increased	Fisk (2006); Tavarini et al. (2008)
3	Ascorbic acid (AA) content	No statistically significant difference, even decreased slightly during storage	Manolopoulou and Papadopoulou (1998)
4	Antioxidant capacity	Significantly decreased	Tavarini et al. (2008)
5	Titratable acidity (TA)	Decreased TA content	Marsh et al. (2004)
6	Starch content	Hydrolyzed to simple sugars	Jordan et al. (2000)
7	pH content	Continuously increased	Fisk (2006)

adopted in other kiwi growing countries worldwide and in the international standard for export (OECD 1992). However, the soluble solids concentration cannot be taken as a reliable index for yellow-fleshed cultivars, where flesh color is more commercial. Flesh color does not correlate with other compositional parameters as it is largely influenced by temperature and other climatic conditions. However, flavor can be linked with soluble solids and also used for harvest indices of early cultivars. It has been reported that dry matter content in kiwifruit mainly composed of starch is highly correlated with soluble solids and soluble sugars after the ripening of fruits (Beever and Hopkirk 1990; Jordan et al. 2000; Crisosto et al. 2008; Jordan and Seelye 2009). Crisosto et al. (1999) proposed that dry matter content is a reliable quality index for kiwifruits, which should be a minimum of 16.1% for consumer acceptance.

Storage

Temperature plays a crucial role in the quality retention and shelf life of kiwifruits during the storage period. High temperature leads to faster metabolic activities, which shortens the shelf life. It is better to store fruits at low temperature in cold stores. The effect of cold storage on quality parameters has been studied by several authors (Table 2). Kiwifruit can be stored at 0 °C with a relative humidity (RH) of 90–95% for up to 6 months (Arpaia et al. 1987; Hewett et al. 1999; Burdon and Lallu 2011). There is a large disparity in the storage period among different cultivars. On one hand, the storage period of the ‘Hayward’ cultivar is around 6 months (Arpaia et al. 1987), whereas on the other hand, ‘Sanuki Gold’

and 'Rainbow Red' cultivars of Japan can be stored only for 1–2 months (Asiche et al. 2017). Nowadays, controlled atmospheric storage has been standardized to store the fruits for longer periods of time. The most ideal and safest temperature for the storage of fruits is 0–0.5 °C. Various researchers have tried to standardize storage conditions under controlled atmospheric storage. McDonald and Harman (1982) reported that 2% O_2 and 5% CO_2 concentration was optimal for the 'Hayward' cultivar, whereas 2% O_2 and 2% CO_2 was found to be suitable for 'Hort16A' kiwi (Lallu et al. 2003).

The relative humidity is also equally important during storage. Because during initial storage days water loss is quick, the maintenance of high relative humidity can minimize this loss. Most commercial growers maintain 90–95% relative humidity in controlled atmosphere (CA) chambers. Besides, the combination and concentration of gases are important. The physiology of fruits is badly affected by an imbalance in gaseous compositions. So, during storage in CA chambers, precise control over gases is a prerequisite. An ideal concentration of oxygen is 2–3% and of carbon dioxide 3–5%, and the ratio of these gases should be maintained. Modern sophisticated CA storage chambers are commercially practiced in China, New Zealand, and Italy by progressive farmers and kiwi promotion societies for improving the shelf life of fruit.

Packaging

Kiwifruit is commonly packed in plastic trays in one-layer flats or in volume-fill or three-layer tray packed lugs. The flats and lugs are lined with a polyethylene plastic sheet or liner that is folded over the packed fruit to protect against water loss. This wrap inhibits the air flow that is needed for rapid cooling of the packed fruit. During packing, the fruit is sized and placed in plastic trays, then covered or wrapped with clear polyethylene plastic, and put in one-layer flats. These packed flats should be cooled quickly so that the fruit core temperature is 32 °F (0 °C) within 24 h of packing, else the storage life will be shortened.

Postharvest Changes in Physicochemical Attributes

Kiwifruit is a highly nutritious, low-calorie fruit with the potential to deliver a range of health benefits (Drummond 2013). Just after harvesting, the fruits undergo various catabolic and anabolic processes, and many physical and compositional changes take place. These changes make them fit for consumption, but, after that, they degrade the quality of produce. These changes start from its development, but, after harvesting, they may hasten by various physiological process and stresses. These changes are discussed next.

Fruit Weight

The loss of weight in fresh fruit is mainly due to the loss of water caused by transpiration, respiration, and vapor pressure deficit between fresh produce and the surrounding air. Kiwifruit may show shriveled symptoms because water is depleted by 3–4% (Fisk 2006). Postharvest water loss can cause rapid deterioration in produce quality through shriveling. However, before shriveling becomes apparent, postharvest water loss may also alter metabolism and, in some instances, hasten fruit ripening (Burdon et al. 2004). Reducing water loss from fruit during storage or ripening therefore helps to maintain fruit quality (Burdon and Clark 2001).

Fruit and Flesh Firmness

Changes in respiration rates after harvest influence the production of ethylene gas during the growing season (Wright and Heatherbell 1967; Pratt and Reid 1974). The harvest time, maturity stage, and storage temperature play a crucial role in fruit softening. Ripening of kiwifruit can be encouraged robustly by ethylene gas at the 5 ppm level. One of the major indicators for maturity of the fruits is firmness, which is influenced significantly by the presence of ethylene gas. Ethylene causes rapid softening in the texture of kiwifruits even at very low concentration (Lallu et al. 1989). The outer pericarp of the fruit softens more rapidly than the core of the fruit (MacRae et al. 1989). Firmness reduction is caused by a stimulation of enzyme pectinesterase activity, which enhances pectin deesterification of the cell wall, as well as loss of solubilized pectin (Wegrzyn and MacRae 1992). Some researchers suggested that enzyme xyloglucan endotransglycosylase may play a key role early in fruit ripening, loosening the cell wall by other cell wall-degrading enzymes (Redgwell and Fry 1993).

Similarly, the flesh firmness significantly decreased during storage independently of the harvest time (Tavarini et al. 2008). It is reported that late-harvested fruits hold their flesh firmness throughout the storage better over early-harvested fruits (Crisosto and Kader 1999). In respect to storage temperature, there is a positive correlation between higher temperature and fruit softening. Kiwifruit stored at 10 °C softened faster than fruits held at 0 °C (Marsh et al. 2004).

Soluble Solids Content

The soluble solids content (SSC) of kiwifruit is considered an index of fruit maturity at harvest and an increase in SSC corresponds to an alteration of starch to soluble sugars (MacRae et al. 1989). The total solids content in fruits ranges between 15.8 and 16.2%. The SSC of kiwifruit is often believed to be linked to consumer test

preference, although a close linkage has not been unequivocally demonstrated or registered (McGlone and Kawano 1998). In addition, fruit with a high SSC at harvest store well and have an acceptable flavor when eaten ripe. At harvest, if fruit contains high SSC, then they can be stored well and with satisfactory flavor (Beever and Hopkirk 1990). In fruits stored at 0 °C for 2 months, the SSC was significantly enhanced compared to storage at 0 °C for 6 months and, thereafter, remains constant (Tavarini et al. 2008).

Total Acid and pH

The total acid content of kiwifruit is in the range of 1.0–1.5% as citric acid (Mitchell et al. 1979; Wildman and Luh 1981), which gets metabolized by the fruit throughout the ripening process. It results in the reduction of total acidity and increase of the fruit pH value. The titratable acidity of fruits continuously decreased from about 1.26% to less than 1% at 42 days after storage, while the pH continuously increased from 3.61 to 3.75 (Fisk 2006).

Starch Content

Starch is a universal polysaccharide present in kiwifruit and ranges from 5 to 8%. The starch content decreases by 70% during the first 2 days of postharvest ripening. It appears that starch is a reserve food in the kiwifruit. When the ripening process begins, the starch is converted into sugars by the activity of amylase enzyme. The major sugars present in kiwifruit are glucose, fructose, sucrose, and a trace amount of sorbitol (Heatherbell 1975). In earlier stages, the biochemical pathway of sucrose synthesis occurs, in which starch is degraded by the enzyme phosphorylase. Later, sucrose breaks into glucose and fructose by the enzyme invertase.

Chlorophylls and carotenoids

Kiwifruit contains significant amounts of chlorophylls as well as carotenoids. There are no major changes in chlorophyll (a and b) in kiwifruit, even after exogenous ethylene treatment. Unlike other fruits, chlorophyllase enzyme is not stimulated by ethylene, and the color/appearance is mostly affected by the starch content. The carotenoids content in harvested kiwifruit improve after 60 days of cold storage, whereas after 180 days of cold storage, fruits shows a significant decrease in carotenoids content (Tavarini et al. 2008).

Ascorbic Acid

Kiwifruit is well known for being a rich source of vitamin C, even more than citrus fruits (Nishiyama et al. 2004). The range of ascorbic acid content in this fruit is 30–300 mg per 100 g fruit (Beutel et al. 1976). It is reported that the ascorbic acid content of the kiwifruit may vary with growing conditions and the degree of ripeness. The ascorbic acid content of the kiwifruit decreased from 210 to 190 mg per 100 g in the ripening process and even more after harvesting. In another study, Tavarini et al. (2008) recorded that the vitamin C concentration in fruits of cv. Hayward decreased at the end of a long period of cold storage. However, the antioxidant capacity is not so good compared to other fruits. Generally, fresh fruits have a greater content of vitamin C than those which have been cold-stored (Lee and Kader 2000). In kiwifruit, there is a considerable reduction in ascorbic acid content during cold storage and, also, the harvest time appreciably influences the ascorbic acid content (Tavarini et al. 2008).

Phenols Content

Generally, the phenols content may either increase or decrease in fruits, depending on the storage conditions (Kalt 2005). It was reported that the total phenols decreased with the increase in storage period in kiwifruit (Jhalegar et al. 2012). Some researchers indicated that there is no significant deviation observed in the phenols content in this fruit during 9 days of storage (Gil et al. 2006). Even after 2 months storage at 0 °C, the phenols content does not change in kiwifruit, but cold storage conditions for longer periods significantly increased total phenolics, and this can be attributed to changes occurring in the phenols metabolism during storage (Tavarini et al. 2008).

Physiological Factors Involved in the Postharvest Deterioration of Kiwifruit

Kiwifruit is a living biological system that is subjected to continuous physiological changes, which cannot be stopped, even after harvest. Changes regarding some quality parameters, like firmness, SSC, sugars, etc., are desirable in respect to the consumer preferences, but their speed of changes can be slowed down to some extent. There are certain physiological factors such as respiration rate, ethylene evolution rate, moisture loss caused by transpiration and chemical changes, etc. that affect postharvest shelf life and quality of kiwifruit.

Respiration Rate

The respiration rate is a major metabolic process that takes place in harvested produce. It is a basic process of life, which is directly related to maturation, handling, transportation, and subsequent storage life. Based on the rate of respiration, Kader (2002b) grouped kiwifruits under low category with 35–70 mg CO_2 kg^{-1} h^{-1} at 20 °C. Similarly, Paull and Duarte (2011) also classified the kiwifruit under 'very low respiring fruits'. The respiration rate of kiwifruit was 3, 5–7, 12, and 16–22 mg CO_2 kg^{-1} h^{-1} at 0, 4–5, 10, and 20–21 °C, respectively. Commodities and cultivars with higher rates of respiration tend to have a shorter storage life than those with lower rates of respiration. An exponential rise in the respiration rate is recorded in green kiwifruit (Antunes and Sfakiotakis 1995), which initially exhibits an increased rate, but, later, the respiration rate stabilizes and remains constant in the range of 10–70 mL CO_2 kg^{-1} h^{-1}. The postharvest sector of the kiwifruit industry considers respiration rate as one of the major possible indicators of storage potential and the respiration rate is known to robustly rely on temperature (Fonseca et al. 2002). Another study indicated a linear relationship between the rate of respiration and temperatures between 1 and 22 °C for gold kiwifruit (Patterson et al. 2003). Respiration rates increased remarkably linearly with equilibration temperature. Conventional wisdom would say that respiration rates should approximately double with each 10 °C rise in temperature (i.e., Q_{10} of 2). A fruit's respiration rate also plays a critical role in the postharvest shelf life and quality. In general, kiwifruit (*Actinidia deliciosa* var. *deliciosa* 'Hayward') is stored commercially at 0 °C for shelf life extension periods before commercial sale.

Ethylene Evolution Rate

Kiwifruit is a climacteric fruit (Wright and Heatherbell 1967), which has minor ethylene content at the time of harvest. This fruit is very sensitive to postharvest ethylene treatment, which shows a distinctive model of increase in ethylene evolution accompanied by a rise in respiration rate (Hyodo and Fukasawa 1985; Park and Kim 1995; Park 1996). As a phytohormone, ethylene regulates many aspects of growth, development, and senescence, and is physiologically active even at <0.1 ppm (Abeles et al. 1992). Very little ethylene concentration (0.005–0.01 μL/L) can stimulate premature ripening and accelerate the texture softening rate, which restricts the shelf life and increases the susceptibility of fruit to handling injuries and development of various fruit rots (Mitchell 1990; Crisosto et al. 2000). Ethylene enhances decay development of fruits by accelerating the senescence and softening processes, and by inhibiting the formation of antifungal compounds in the host tissue (Kader 1985). The ethylene evolution rate is directly dependent on the respiration rate and temperature. The rate of ethylene production is almost zero at temperatures below 10 °C in kiwifruit (Antunes et al. 2000), but it increases

substantially between 30 and 34 °C and declines above 40 °C (Antunes and Sfakiotakis 2002). Ethylene induces fruit abscission, softening, ripening, and some physiological disorders as well (Abeles et al. 1992). The production of ethylene by the kiwifruit is triggered through exogenous exposure of ethylene, mechanical injury, even small surface wounds, or pathogen attack or a diseased fruit (Sfakiotakis et al. 1997). Based on the rate of ethylene evolution, Kader (2002a) grouped kiwifruits under high, i.e., 10.0–100.0 μL, C_2H_4 kg^{-1} h^{-1}, at 20 °C temperature. Numerous factors affect the rate of ethylene evolution, including species, cultivar, maturity, and ripening (especially in climacteric fruits), temperatures, physical/mechanical damages, diverse types of stresses such as water stress, microbial attack, storage temperature, storage period, and the gaseous composition of the storage container. Mechanical injuries in minimally processed fruits resulted in triggering the rates of respiration and ethylene production within minutes (Abe and Watada 1991). During storage, such products have a very limited shelf life (Brackett 1994; O'Connor-Shaw et al. 1994). These responses occur in disrupted tissues, where cellular decompartmentation leads to intermixing of enzymes and substrates, as well as release of acids and hydrolyzing enzymes (Watada et al. 1990). The age of the fruit at harvest (number of days after pollination) plays an important role in the initiation of ethylene production.

Transpiration and Water Loss

Transpiration is a physical process in which water is lost in the form of vapor and also causes reduction in fruit weight. The rate of transpiration (evaporation of water from the plant tissues) is influenced by internal or commodity factors (morphological and anatomical characteristics, surface-to-volume ratio, surface injuries, and maturity stage) and external or environmental factors (temperature, relative humidity, air movement, and atmospheric pressure); for example, high temperatures, low RH, and high air velocity promote high water loss. Water loss (shriveling) is recognized as the most important cause of commercial fruit deterioration in kiwifruit during storage (Hassall et al. 1998), because it results not only in direct quantitative losses (loss of salable weight) but also in losses in appearance (wilting and shriveling), textural quality (softening, flaccidity, limpness, loss of crispness, and juiciness), and nutritional quality. In particular, loss of fresh weight (water loss) can also speed up ascorbic acid degradation (Tavarini et al. 2008). Kiwifruits are considered more susceptible to water loss. When kiwifruits are kept under relative humidity below 92–95%, they lose a significant amount of water. The lower the relative humidity, the greater the moisture loss. Transpiration can be controlled by applying treatments to the commodity (e.g., waxes and other surface coatings, and wrapping with plastic films) or by manipulating the environment (e.g., refrigeration, maintenance of high relative humidity, and control of air circulation) (Kader 2002a).

Phytohormones

The physiological role of various phytohormones to regulate the growth, development, maturity, ripening, and senescence of fruit has been established by various researchers. Gibberellic acid can promote auxin action, while high doses of auxin can increase ethylene production (Burg 1968). Auxins are mainly responsible for cell enlargement by increasing water uptake and, thereby, increasing the extensibility of cell wall. Ohara et al. (1997) studied the seasonal changes in endogenous levels of growth substances in kiwifruit. They reported that the levels of indole acetic acid-like substances in the seeds correlated with fruit development and it tended to increase towards maturation. The seasonal levels of gibberellic acid and cytokinin like substances in the seeds correlated with initial rapid development of the fruit and seed tissues, whereas abscisic acid-like substances might be associated with maturation because its levels in the seeds and flesh increase towards harvest. The application of auxins in the form of 2, 4-dichlorophenoxyacetic acid applied at 25 ppm concentration at 43 days after full bloom has been found to be the most effective treatment in increasing fruit size, weight, and production in kiwifruit (Lorenzo et al. 2006). Cytokinins have been shown to promote the reversal of senescence by stimulating the expression of genes for the redifferentiation of senescent plastids (gerontoplasts) into chloroplasts (Robson et al. 2004). In green kiwifruit, a peak of cytokinin activity occurs during the cell division phase (Lewis et al. 1996). In addition, a significant amount of cytokinin was detected in mature fruit (Lewis et al. 1996). It is hypothesized that the differential degreening in green and gold kiwifruit may be a consequence of differential activity associated with cytokinins. Salicylic acid (SA) delays kiwifruit ripening and senescence by retarding its climacteric ethylene rise (Zhang et al. 2003), preventing the softening process, maintaining flesh firmness, improving physicochemical properties like ascorbic acid content, total soluble solids, and helping in the retention of green color during storage (Solaimani et al. 2009; Wang et al. 2006; Fattahi et al. 2010).

Environmental Factors Affecting Deterioration

Some environmental factors are also responsible for deteriorating the postharvest quality and shelf life of kiwifruits, such as temperature, light, relative humidity, oxygen, carbon dioxide concentration, etc., and are discussed below.

Temperature

The most important factor affecting postharvest life of this fruit is temperature, because it has a profound effect on the rates of biological reactions; for example, metabolism and respiration (Marangoni et al. 1996). The physiological range of

temperature for most of the fruit crops is 0–30 °C (32–86 °F), whereas any deviation from this range may cause a significant change in metabolic activity, such as respiration rate. Fruit respiration rates are known to be strongly dependent on temperature (Fonseca et al. 2002). Various studies have shown that temperature has a profound and direct influence on the respiration rate of kiwifruits. There is a slow decline in the respiration rate from 9 to 8 mL CO_2 kg^{-1} h^{-1} that occurs at a temperature of 20 °C over the initial 8 days, thereafter dropping more rapidly to about 4.0 mL CO_2 kg^{-1} h^{-1} after 20 days, when the fruit reaches senescence (Wright and Heatherbell 1967). The rate of ethylene evolution also increases in rotten fruits during storage (Asiche et al. 2017).

Light

Light is the environmental aspect that is a significant determinant of fruit yield as well as quality of many crops, such as apple, grape, and kiwifruit (Tustin et al. 2001; Xiloyannis et al. 2002). Therefore, an adequate number of leaves should be on the tree. Leaf area exposed to the sun must be plenty in order to supply the carbon required for both fruit as well as vegetative growth during the day time and, also, appropriate light (intensity and quality) and temperature do influence the postharvest eating quality (Kays 1999). The higher the intensity of light during the growing season, the greater the vitamin C content in plant tissues (Lee and Kader 2000). It was also proposed that light has a role in enhancing Ca accumulation in fruits exposed to bright sun compared to fruits that remain in the shade in kiwifruit. The exposure to full sun induces hydroxycinnamic acids concentration increases of up to 30% over shaded fruit, which protects auxin producers. Light induces the biosynthesis of such phenols, indirectly reduces auxin degradation, and, ultimately, increases Ca accumulation (Faivre-Rampant et al. 2002; Montanaro et al. 2006).

Relative Humidity

Water loss from harvested fruits is predominantly caused by the amount of moisture present in the ambient air, which is expressed as relative humidity. At very high relative humidity, harvested fruits maintain their nutritional quality, appearance, weight, and flavor. Relative humidity also plays a positive role in maintaining the temperature in the environment and also decides the water loss through transpiration from the fruits. The rate of water loss from the fruit depends on the RH at a particular temperature and air movement near the fruits. At a given relative humidity, water loss increases with the increases in temperature (Kader 2002a).

Atmospheric Gases

The combination of different gases in a storage environment is very important in extending the storage life of fruits. Among different gases, oxygen and carbon dioxide play crucial roles in maintaining the proper metabolic activity within the fruit under storage atmosphere. Sufficient O_2 levels are essential to maintain aerobic respiration in the fruits. Enhancement of the CO_2 concentrations around some commodities minimizes respiration, retards senescence, and slows down microbial growth. However, improved CO_2 levels can promote fermentative metabolism with low O_2 levels in the environments. The commonly used CO_2 concentration is 2–5%, in controlled or modified atmospheric storage, and has been exhibited to prevent kiwifruit softening in combination with low O_2 (Lallu et al. 2003).

Nutrients

Mineral nutrients can influence the quality of horticultural crops in many ways, particularly physiological fruit disorders (Ferguson and Boyd 2002). Preharvest nutrient application affects the postharvest quality and shelf life of kiwifruit. Among macronutrients, higher doses of nitrogen fertilizers reduce the ascorbic content in many fruits (Lee and Kader 2000). It was reported that excess nitrogen content at the time of harvest was associated with greater incidence of *Botrytis* rot and rapid fruit softening during storage (Johnson et al. 1997). Among the secondary major nutrients, it is well known that calcium plays a significant role in maintaining quality in a number of different fruits, as well as in kiwifruit (Ghani et al. 2011; Montanaro et al. 2006; Tagliavini et al. 1995), because of its function in the cell wall and the resulting influence on the shelf life of fruit (Bauchot et al. 1999). Calcium changes intracellular and extracellular processes, thereby retarding the ripening process by lowering the rates of color change, softening, CO_2 and ethylene production, reduction in total acid content, and increase in sugar content (Souty et al. 1993). The earlier study showed that the preharvest calcium chloride and calcium chelate application of kiwifruit improves firmness during storage by reducing softening (Xie et al. 2003; Antunes et al. 2005). The postharvest dipping of kiwifruit in 2% $CaCl_2$ benefits storage life (Antunes 2007). Some mineral elements, such as calcium, magnesium, and nitrogen, may also be involved in postharvest quality and decays (Spadaro et al. 2010). Lower calcium content contributes to favorable conditions to infections and physiochemical disorders, and, consequently, of a higher incidence of postharvest diseases (Biggs 1999).

Postharvest Quality Loss in Kiwifruits

Chilling Injury

Low temperature may cause chilling injury that leads to membrane degradation, such as hydrolysis of membrane phospholipids to constituent free fatty acids, and peroxidation of constituent polyunsaturated fatty acids with a corresponding production of free radicals. Kiwifruit showed an increase in electrolyte leakage over a few days of chilling up to 15% when exposed at −2 °C for 40 h (Gerasopoulos et al. 2006). Low-temperature sensitivity depends on the genetic constituents of the cultivar. The fruit of *Actinidia deliciosa* cv. 'Hayward' are chilling-sensitive at temperatures near 0 °C, with symptoms appearing as a ring or zone of granular, water-soaked tissue in the outer pericarp at the stylar end of the fruit. Also, some chilling-sensitive crops exhibit more losses in ascorbic acid content at lower temperatures (Lee and Kader 2000). Exposure of kiwifruit to chilling temperatures (0–10 °C) for 2 weeks enhances ethylene biosynthesis and ripening upon rewarming of the fruit in comparison to fruit kept at 20 °C (Antunes and Sfakiotakis 2002). Sanuki Gold' and 'Rainbow Red' are more sensitive to low temperatures compared to 'Hayward', and the sensitivity is involved in the determination of storage life and how early the fruit matures on the vine (Asiche et al. 2017). Low-temperature breakdown, a disorder which causes considerable quality losses during prolonged cold storage in kiwifruit, appears to be related to factors affecting membrane function (Sfakiotakis et al. 2005; Gerasopoulos et al. 2006; Antunes and Sfakiotakis 2008).

Heat Injury

When temperature reaches beyond the optimum level, the rate of respiration falls. It becomes negative as the tissue nears its thermal death point and enzyme proteins are denatured. Due to high temperature (30–40 °C), there occurs water loss and shriveling in kiwifruit, which stimulate ethylene production (Antunes et al. 2000).

Mechanical Damages

Among different causes of damage to fruits, vibration generated by vehicles during road transport plays an important role in the damage process to the agricultural products, particularly soft fruits (Acican et al. 2007). Mechanical damage which occurs during different stages of fruit harvest and postharvest represents a serious hazard to quality and has the potential to significantly reduce the value of product (Van Zeebroeck et al. 2007). The occurrence of damage to kiwifruits during transport is related to a number of factors, of which the most important is the fruit resistance to mechanical damage due to vibration. The vibrations due to transportation are

influenced by road roughness, distance, speed, packaging, and some characteristics of the truck suspension and the number of axles (Vursavuş and Özgüven 2004).The three factors which can physically cause fruit bruising are impact, vibration, and compression load (Vergano et al. 1991). The mechanical damages considerably increased by increasing the vibration frequency and acceleration. The larger kiwifruits are more prone to damage than the smaller ones during transportation. The total damage considerably increased by increasing the stack heights of fruits inside the bin (Tabatabaekoloor et al. 2013). Kiwifruit bruise damage is a common postharvest problem that substantially reduces fruit quality and marketability. Fruit bruising causes tissue softening and makes them more susceptible to undesired agents, such as diseases-inducing agents (Ahmadi 2012). It is reported that greater injury occurs in larger sizes of kiwifruits. Increasing the vibration frequency and acceleration increased the total percentage of damage to kiwifruits. The most damage to kiwifruits occurred at a vibration frequency of 13 Hz, vibration acceleration of 0.7 g, stack height of 34 cm, and large size of kiwifruits. The effect of frequency and acceleration were more critical when the stack height increased (Tabatabaekoloor et al. 2013).

Other Disorders

Kiwifruit is also prone to several minor disorders. Hard core affects the fruit ripening process and is caused mainly by high exposure to ethylene and CO_2. The other most important disorders are freezing damage, internal breakdown, pericarp granulation, and translucency, which alter the quality and storability of fruits during cold storage (Crisosto et al. 1999).

Postharvest Diseases

Kiwifruits are susceptible to several microbial disorders. The important ones are described below.

Fungal Rots

During storage, fruit rots can cause serious economic losses (Spadaro et al. 2010), and *Botrytis cinerea*, the causal agent of gray mold rot, is the most important postharvest pathogen (Pyke et al. 1994). In addition to *Botrytis cinerea*, *Botryosphaeria dothidea* and *Diaporthe actinidiae* have been identified as the major fungal pathogens causing soft rot decay during postharvest storage in New Zealand (Bautista-Baños et al. 1997) and Korea (Lee et al. 2001).

Botrytis gray mold rot is posing the greatest threat in kiwifruit marketing, caused by the fungus *Botrytis cinerea* (Sommer et al. 1983). This disease occurs in kiwi-

fruit from all growing areas, including New Zealand, USA, Chile, Greece, and Italy (Crisosto et al. 1999). Kiwifruit becomes much more susceptible to *Botrytis* (and other fungi) as they soften. Thus, maintaining fruit firmness (by rapid cooling, cold storage, and use of controlled atmospheres) can significantly reduce pathological breakdown.

Bacterial Canker

Bacterial canker of kiwifruit caused by a virulent strain of *Pseudomonas syringae* pv. *Actinidiae* is having a major effect on kiwifruit industries throughout the world (Costa and Ferguson 2013).

Various Postharvest Treatments for Quality Improvement

Fruits deteriorate rapidly after harvest and, in some cases, do not reach consumers at optimal quality after transport and marketing. The main causes of fruit deterioration are dehydration, with the subsequent weight loss, color changes, softening, surface pitting, browning, loss of acidity, and microbial spoilage. However, the deterioration rate is affected by different factors, such as intrinsic characteristics of the product and storage conditions in terms of temperature, relative humidity, storage atmosphere composition, etc. The main objective of postharvest technology is quality optimization and reduction of losses along the postharvest chain, in which existing technologies are being complemented with revolutionary new ones such as 1-methylcyclopropene (1-MCP) or active packaging, as well as some emerging technologies. Among the classical technologies, low-temperature storage, heat treatments, and modification of the stored atmosphere are the most common. There are some interesting technologies at the research level but with promising futures, such as calcium and polyamine treatments, and some emerging technologies like biological control, atmospheres with high O_2, and the use of UV light. Some recent trends in postharvest treatments are depicted in Table 3.

Calcium Treatment

Pre- and postharvest calcium applications have been demonstrated to produce beneficial effects on whole fruit quality, decreasing the incidence of physiological disorders and fungal decay. The ultimate objective of calcium applications, as with any other postharvest treatment, is to maintain it for as long as possible. Gerasopoulos and Drogoudi (2005) observed that preharvest $CaCl_2$ spray reduced low-temperature breakdown along with maintaining higher firmness, soluble solids, and high Ca content.

Table 3 Effects of different postharvest treatments on the quality and storage of kiwifruits

Treatments	Effect on quality	References
Calcium treatment and preharvest $CaCl_2$	• Increase firmness, shelf life, and acceptability by lowering physiological disorders • Higher SSC, Ca content, and shelf life	Gerasopoulos and Drogoudi (2005)
Polyamines	Delayed ripening and minimized chilling injury	Martínez-Romero et al. (2007)
Methyl jasmonate (MeJA) and methyl salicylate (MeSA)	Inhibit lignifications	Li et al. (2017)
1-MCP	• Inhibit softening and higher firmness	Lim et al. (2016)
	• Delayed softening and suppressed ethylene production rate	Boquete et al. (2004); Koukounaras and Sfakiotakis (2007)
	• Maintained higher firmness, ascorbic acid, and phenolics in hardy kiwifruits	Lim et al. (2016)
Harpin along with *Candida diversa*	Reduced gray (*B. cinerea*) and blue mold (*P. expansum*) infections and induced defense-related enzymatic activities	Tang et al. (2015)
Aloe vera coating	Maintained firmness, ascorbic acid yellowing due to ripening	Benítez et al. (2015)
Chitosan coating	Prevent decay loss	Du et al. (1997); Fisk et al. (2008)
Hot water treatment at 45 °C	Reduced chilling injury index and disease incidence in Hongyang kiwi	Ma et al. (2014)
Low-temperature conditioning	Alleviated chilling injury, enhances activity of defense-related enzymes, and reduced respiration and ethylene evolution rate	Yang et al. (2013)
Salicylic acid and KMnO4	• Delayed the ripening of kiwifruits	Bal and Celik (2010)
Pre- and postharvest oxalic acid treatment	• Induced fruit russet elimination, fruit firmness, SSC, and shelf life of fruits	Zhang et al. (2006)
Ozone treatment along with cold storage	Had fungicidal effect on *Botrytis cinerea*, firmness, and acidity decreased, whereas sugars increased	Barboni et al. (2010)
	• Inhibited AdACS1 and AdACO1 expression, inhibition of cell wall degrading enzymes activity	Minas et al. (2014)

Polyamines

Polyamines (PAs) (putrescine, spermidine, and spermine) are plant growth substances which could be used for delaying the ripening process and other physiological activities in kiwifruits (Martínez-Romero et al. 2007). Additionally, PAs reduce some type of stresses, such as chilling injury and mechanical damage. Jhalegar et al. (2012) reported that the fruits treated with spermine (1.5 mM) and spermidine (2.0 mM) had better shelf life and the least enzymatic activities when stored at

22 ± 4°C and relative humidity (65 ± 5%). Petkou et al. (2004) investigated a comparative study of polyamine treatment through vacuum, dipping, and pressure infiltration methods. They reported that pressure infiltration delayed the ripening rate, ethylene evolution, and respiration rate of kiwifruits.

1-Methylcyclopropene

1-Methylcyclopropene (1-MCP) is a cyclic olefin which inhibits the action of ethylene. 1-MCP treatment in kiwifruits reduces the respiration and ethylene evolution rate and delays the ripening process. Prestorage application of 1-MCP significantly reduced the rate of CO_2 production, delayed ripening, softening of fruits, and decay due to *Botrytis cinerea* during storage at 20 °C for 14 days (Koukounaras and Sfakiotakis 2007). Similarly, cultivar Hayward treated with 0.5 μL L^{-1} 1-MCP showed suppressed ethylene, delayed softening, and low soluble solids content (Boquete et al. 2004). Lim et al. (2016) reported that hardy kiwifruits *(Actinidia arguta*) retarded the ripening process and delayed respiration when treated with 20 μL L^{-1} 1-MCP for 16 h at 10 °C. They found higher shelf life in treated fruits for up to 5 weeks with higher firmness, ascorbic acid, and total phenolics content. Li et al. (2017) reported that fewer lignifications were observed in fruits treated with methyl jasmonate (MeJA) and methyl salicylate (MeSA), whereas fruits treated with 1-MCP showed enhanced activities of phenylalanine ammonia lyase (PAL) and peroxidase (POD) enzymes, along with lignifications at 0 °C.

Coating

Coating of fruits with different edible coatings reduces the rate of ripening and respiration, and maintains quality, along with storability. *Aloe vera* coating reduced the yellowing and ripening process with maintaining higher firmness and ascorbic acid (Benítez et al. 2015). Diab et al. (2001) concluded that pullulan-based coatings retarded water loss in kiwifruits. Chitosan coating prevented moisture loss and prevented decay loss from whole kiwifruits (Du et al. 1997; Fisk et al. 2008). Edible coating of soy protein concentrate reduced the process of senescence in whole kiwifruits (Xu et al. 2001).

Bioagents

Postharvest disease attack causes significant loss in terms of quality and quantity in kiwifruits. The use of bioagents to control diseases is a new ecofriendly, nonchemical approach which is gaining popularity among researchers. The use of

single bioagents or in combination with yeast and other safe chemicals are more effective and promising nowadays (Cook et al. 1999). Tang et al. (2015) applied *Candida diversa* or harpin alone and in combination, which significantly reduced gray mold (*B. cinerea*) and blue mold (*Penicillium expansum*) infections, and enhanced the activities of defense-related enzymes in kiwifruit.

Hot Water Treatment and Low-Temperature Conditioning

How water treatment (HWT) is an effective technique to reduce postharvest loss during the storage of fruits. Many researchers reported that HWT is a valuable postharvest technology for enhancing chilling tolerance and maintaining fruit quality. Ma et al. (2014) reported that prestorage hot water (45 °C) treatment for 10 min was found to be best as compared to temperatures of 35 and 55 °C. Fruit treated at 45 °C showed lower ethylene, malondialdehyde content, and lipoxygenase activities, with retention of higher fruit firmness and soluble solids. Low-temperature conditioning is another way to minimize chilling injury in kiwifruits. Low-temperature conditioning (12 °C for 3 days) maintained higher firmness, lowered ethylene, respiration, and chilling tolerance, and increased the activity of defense-related enzymes (Yang et al. 2013). In addition to this, it also induced an endogenous level of hormones.

Ozone Treatment

Ozone is a well-known oxidizer of ethylene and has commercial importance in the food industry. Recently, the application of ozone during the storage of fruits gained popularity due to its high sensitivity towards ethylene. Ozone-treated fruits delayed ripening due to checking ethylene biosynthesis (Minas et al. 2014). Barboni et al. (2010) found that ozone-treated fruits reduced the incidence of *B. cinerea* on the surface of fruits and induced the amount of total sugars during the entire period of storage.

Oxalic Acid (OA) and Salicylic Acid (SA) Treatment

Oxalic acid induces systemic resistance mechanism against postharvest diseases. OA is used to minimize disease incidence in fruits and vegetables. OA treatment induces storability and fruit russeting in kiwifruits (Zhang et al. 2006). Fruits treated with preharvest OA (5 mM) maintained higher fruit firmness, ascorbic acid, and higher soluble solid concentration during storage (Zhu et al. 2016). Likewise, the

use of salicylic acid is also an effective method to extend the shelf life of fruits and vegetables.

Conclusion

Kiwifruit is an economically important fruit crop and is highly appreciated for its high concentrations of bioactive compounds. 'Hayward' is the most popular cultivar, which suits most of the consumer and industry needs. Kiwifruit is classified under climacteric fruits; hence, it is deteriorated rapidly after harvesting due to rapid ripening, associated softening, and fungal rotting. Reliable and cultivar-specific maturity indices are not available, except for the soluble solids content. Fruits are highly sensitive to ethylene, so the rapid production of ethylene during ripening leads to shorter shelf life and early ripening. The application of novel techniques, edible coating materials, ecofriendly chemicals, and safe storage techniques like CA storage could help in the retention of quality attributes, consumer acceptability, and longer shelf life during the supply chain. However, limited research work has been carried out in this regard, which needs to be addressed in the future. The postharvest physiology of fruits requires more attention at the genetic and molecular levels in order to understand the developmental process and better implement postharvest management techniques.

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Postharvest Biology and Technology of Strawberry

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Introduction

Strawberry belongs to the family Rosaceae and the genus *Fragaria*. It is cultivated in plains as well as in the hills up to an elevation of 3000 m in humid or dry regions. They are native to the temperate regions of the northern hemisphere, and developed varieties are widely grown throughout the world. In India, strawberry cultivation extends from temperate to subtropical regions, and it behaves as an annual in subtropical regions and perennial in temperate regions. Strawberry is produced in 71 countries worldwide and is among the highest-yielding fruit crops (Husaini and Abdin 2007). The annual production of strawberry fruit is 8.11 million tons with the highest production in the United States, Mexico, Turkey, Spain, and Egypt (FAOSTAT 2017). Botanically, it is described as an aggregate fruit, wherein many one-seeded achenes are embedded in a swollen, fleshy, red receptacle. The sizably voluminous, fleshy receptacles are the succulent edible portions of the fruit. Strawberry for commercial purposes has a red color outside and inside shading ranging from white to dark red. Fruit shape and size varies depending upon factors like variety, environmental conditions under which it was grown, planting area, fertilizer dose, etc. (Smith et al. 2003).

Strawberries are sought all over the world due to their high nutraceutical profile and commercial value (Bhat and Stamminger 2015). Strawberry is not only famous for its cute appearance, but also for its spectacular nutritive figures, which include essential nutrients and beneficial phytochemicals. Strawberries are considered a potentially good source of vitamin C and are rich in a wide array of bioactive compounds, such as polyphenols, flavonoids, anthocyanins, and tannins (Battino et al. 2009; Tulipani et al. 2009; Giampieri et al. 2012, 2013). However, the composition of strawberries varies depending on the individual genotypes, cultivar, environment

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factors of the growing regions, maturity stage during harvest, as well as pre- and postharvest agricultural practices (Aaby et al. 2012).

Strawberries must be picked at or near the fully ripe stage to obtain the best eating quality. Their respiration rate is high and increases two- to three-fold when the temperature is between 10 and 20 °C. The exceptionally high respiration rate can be attributed to fast postharvest deterioration. Harvest season, maturity stage, temperature, duration of storage, and packaging influence the quality and shelf life of strawberries (Mingchi and Kojimo 2005; Panda et al. 2016). Strawberry fruit has a very short shelf life and senescent period, due to its susceptibility to mechanical injury, excessive texture softening, physiological disorders, and infection caused by several pathogens that can rapidly reduce the quality of fruit, and which make marketing a challenge (Vu et al. 2011). Several preservation techniques such as refrigeration, modified atmosphere packaging, and heat treatments have been studied to extend the shelf life of fresh strawberries.

Maturity and Ripening

Fruit maturity is the main index for the sorting and harvesting of strawberry crop. In the traditional method, the fruit changing to red indicates ripeness of strawberries. Liming and Tiezhong (2007) developed a new method to confirm the mature stage, which is the red degree from light red to black red on the strawberry surface. The quality components of strawberry include appearance (color, shape, size, freedom from defects, and decay), firmness, flavor, and nutritional value. Color, firmness, flavor, nutritive value, and safety of strawberries are related to their composition at harvest and compositional changes during postharvest handling. These factors have been identified as important contributors to the overall quality of strawberry fruit (Shamaila et al. 1992). Montero et al. (1996) evaluated various quality parameters to indicate the optimum harvest date for the cultivar ‘Chandler’. The results showed that the best quality characters were within the period of 28–35 days from fruit set. From the data, it is possible to predict that the strawberry fruits are at the best stage of development and ripening on day 28 from fruit set.

Generally, flavor is one of the most important properties that give commercial value to fruits. Strawberry flavor is balanced by sugars and acids expressed in ripe fruits. The attractive colors are due to sugar derivatives of anthocyanidins. Pigments are important esthetic components, being natural indicators of ripeness. Due to the large genotypic variations in strawberry composition, it is possible to develop new cultivars having good eating quality and can withstand postharvest handling (Kader 1991). The texture of fruits is governed by structural polysaccharides (pectic substances). The loss of firmness during ripening is a major factor determining strawberry fruit quality and postharvest shelf stability. The complex relationship between carbohydrate composition, cell structure, and the physical property of the whole tissue is further complicated by increase in cell volume, which continues throughout ripening (Manning 1993). As strawberry fruit ripens, an increase in anthocyanin content is accompanied by decreases in firmness and chlorophyll content. The

increase in anthocyanin content coincides with the induction of the activities of phenylalanine ammonia-lyase and uridine diphosphate glucose (Given et al. 1988). Acids can affect flavor directly and are also important in processing. They affect the formation of off-flavors, gelling properties of pectin, and also regulate cellular pH. The predominant acids in strawberry are citric and malic acids. Glycolic and shikimic acids are also present, but in lower quantities.

Strawberry has been classified as a non-climacteric fruit, showing no increase in the respiration rate or ethylene production during ripening. It is also because of the inability to accelerate strawberry fruit ripening by the external application of ethylene or ethylene-releasing compounds. Despite low levels of this hormone in the fruit, ethylene presents a characteristic pattern of production during different developmental stages. It is moderately high in green fruits, decreases in white fruits, and, eventually, increases at the red stage of ripening (Perkins-Veazie et al. 1996; Leshem and Pinchasov 2000; Iannetta et al. 2006). Strikingly, this last increase is accompanied by an enhanced respiration rate which resembles that of climacteric fruits at the onset of ripening (Iannetta et al. 2006). Moreover, postharvest color changes in three-quarters, colored and full-red strawberries have driven a few researchers to propose that strawberry might be a climacteric rather than an absolute non-climacteric fruit. The compositional changes with ripening include increase in soluble solids, total sugars, total ascorbic acid, pH, and water-soluble pectins; and decrease in acidity, total phenols, total pectin, cellulose, and activities of polyphenol oxidase and peroxidase (Spayd and Morris 1981).

Many pre- and postharvest factors influence the composition and quality of strawberries. These include genetic, environmental factors and cultural practices. Sunny days and cool nights produce better flavored strawberries than cloudy, humid, and warm nights (Sistrunk and Morris 1985). Inadequate light intensity reduces ascorbic acid, pH, color, and soluble solids. Excess levels of nitrogen applied to plants decrease firmness, total soluble solids, and flavor (Sistrunk and Morris 1985).

Composition of Strawberry

Strawberries are a nutritious fruit with putative health benefits, because of their rich content of nutrients, with unique color, flavor, and taste. Strawberry fruit is good source of vitamin C and folate. Moreover, it is also a source of several other vitamins, such as thiamin, riboflavin, niacin, vitamin B_6, vitamin K, vitamin A, and vitamin E, though to a lesser extent (Giampieri et al. 2012).

Strawberry is rich in polyphenols and, as it is consumed in high quantities, it can be a valuable source of phenolic compounds in the diet. The main phenolic compounds in strawberries are anthocyanins, flavonols, flavanols, derivatives of hydroxycinnamic acid, and ellagic acid (Aaby et al. 2007, 2012). Many studies have reported the total anthocyanin content to be from 150 to 600 mg/kg of fresh weight (Lopes-da-Silva et al. 2002; Castro et al. 2002). Some investigators have found values of up to 800 mg/kg of fresh weight (Garcia-Viguera et al. 1998).

Flavanols are the only class of flavonoids that do not occur naturally as glycosides. They are present in strawberries in monomeric (catechins) and polymeric forms, called condensed tannins or procyanidins (Aaby et al. 2007). Strawberries also contain a selection of phenolic acids that emerge as derivatives of hydroxycinnamic acid (i.e., caffeic acid) and hydroxyl benzoic acid (i.e., gallic acid) (Mattila et al. 2006; Aaby et al. 2007).

Phytosterols are plant-derived sterols that have structural and functional similarities to cholesterol. Jimenez-Escrig et al. (2006) mentioned that strawberry was recognized as a fruit source of phytosterols in the Spanish diet, providing approximately 0.7 mg of the total phytosterols obtained from a daily intake of 6 g of strawberries.

Cold Storage

Strawberries are extremely perishable fruit with a storage life of 1–2 days at room temperature (Garcia et al. 2011). Temperature management is one of the most important factors in minimizing the deterioration of the strawberry fruit. Higher storage temperatures result in higher respiration rates and shorter storage periods, which are, in turn, associated with the loss of fruit quality (Ayala-Zavala et al. 2004; Cordenunsi et al. 2005). The most pervasive technique for keeping up quality and controlling decay is rapid cooling after harvest and storage at low temperatures (Han et al. 2004).The shelf life of fresh strawberries at cold temperature (0–4 °C) is usually around 5 days (Vargas et al. 2006). It is, therefore, important to apply an appropriate postharvest treatment to delay respiration, prevent physical damage and dryness, and to restrict fungal decay in order to extend shelf life.

Low temperature can extend the marketable life of fruits by delaying the natural aging process considerably (Bohling 1986). Also, at low temperature, the development of postharvest pathogens is slow, while rapid growth occurs when the fruit is stored at ambient temperature (Sommer et al. 1973). Among other postharvest techniques, a rapid postharvest cooling process is the most important factor to maintain the quality and enhance the shelf life of fresh strawberries (Kader 2002). Many researchers (Nielsen and Leufvén 2008; Choi et al. 2016; Giuggioli et al. 2015; Caner et al. 2008) have reported that strawberries should be kept at low temperatures near 0 °C and at high humidity after harvest, as they have a fast metabolism which leads to rapid senescence. Harvey et al. (1980) reported that strawberry temperatures during commercial transport actually ranged from 2 to 9 °C.

Controlled Atmosphere Storage

Controlled atmosphere (CA) storage involves maintaining an atmospheric composition that is different from air composition. Atmosphere modification should be considered as a supplement to the maintenance of optimum ranges of temperature and

relative humidity for each commodity in preserving the quality and safety of fresh fruits. Almenar et al. (2006) examined the effect of controlled atmosphere storage to extend the shelf life of 'Reina de los Valles', a wild strawberry fruit variety, and concluded that the shelf life of berries can be extended by exposing the fruit to cold environment and an adequate atmosphere composition. After storing fruits in different atmosphere compositions, the results showed that a 10% CO_2 and 11% O_2 combination can efficiently prolong the shelf life of wild strawberries by maintaining the quality parameters within acceptable values, through inhibiting the development of *Botrytis cinerea*, without significantly modifying consumer acceptance. Li and Kader (1989) found that, during the storage of strawberry fruit cv. 'Selva' at 2 °C, O_2 level of 0.5% and CO_2 in the range of 15–20% was more effective in decreasing the rate of respiration. Reduction in the rate of respiration can help in minimizing the compositional changes during storage, which could better maintain the taste and nutritional value of fruit. The main benefit from CA for strawberries is the control of gray mold caused by *Botrytis cinerea*, which is the most serious postharvest disease of strawberry fruit (Maas 1984). Couey et al. (1966) found that decay caused by *Botrytis cinerea* was decreased by reducing the ambient O_2 concentration to 0.5% or less. Also, Couey and Wells (1970) found that decay control in CA storage is due to elevated CO_2levels (≥10%). CA storage has also been tested for insect control (Aharoni et al. 1979). Concentration ranges of 5–10% O_2 and 15–20% CO_2 have been recommended as optimal for CA storage of strawberries at a storage temperature of 0 °C (Kader 1992). Moreover, in CA storage, CO_2 and O_2 may be adjusted to maximize their beneficial effect on individual quality parameters, depending on the anticipated temperature during postharvest handling (Nunes et al. 1995).

Modified Atmosphere Packaging

An inexpensive tool that is an alternative to CA storage is the use of modified atmosphere packaging (MAP). MAP may be used to maintain the favorable environment within a sealed package until the product is sold, and it can be a supplement to proper temperature maintenance in the effort to delay ripening (Giuggioli et al. 2015). MAP can be carried out by sealing fresh strawberries in polymeric film packages that modify the O_2 and CO_2 levels within the package atmosphere (Zheng et al. 2008). Several authors (Fishman et al. 1996; Hirata et al. 1996) concluded that combinations of polymeric and perforated films could potentially provide adequate fluxes of O_2 and CO_2 for commodities such as strawberries having high respiration rates. Emond and Chau (1990) presented the concept of perforation-mediated MAP and Emond et al. (1991) simulated the use of this packaging system in strawberries. Sanz et al. (2002) assessed the capacity of the microperforated packaging system for strawberry and found that fruit quality was kept for 10 days at 2 °C. Choi et al. (2016) reported that the shelf life of 'Maehyang' strawberry could be extended by CO_2 treatment alone or a combination of CO_2 and MA. The optimal gas

composition of the MAP test for strawberries was found to be 2.5% O_2 and 16% CO_2 (Sandhya 2010; Giuggioli et al. 2015).

Modeling of transport and biological phenomena occurring inside modified atmosphere packages has turned into a useful tool in MAP design. It allows the prediction of package performance through the analysis of the interaction that happens between produce respiration, O_2 and CO_2 permeation through packaging film, and storage temperature fluctuations (Rennie and Tavoularis 2009). Rennie and Tavoularis (2009) tested two distinctive respiration rate models in a simulation of perforation-mediated MAP of strawberries (cv. Oso Grande) and found significant differences in the resulting gas composition inside the package, reinforcing the importance of obtaining accurate respiration rate data for the given variety and conditions of the stored commodity. Hertog and Banks (2003) focused on the relevance of a systematic characterization of different products respiration rate, as a function of at least O_2, CO_2, and temperature, to enable a fundamental approach to MAP design. Respiration rate models encountered in the literature take into account gaseous composition and temperature effects (Torrieri et al. 2010). Barrios et al. (2014) developed a model for strawberry (cv. San Andreas) and respiration rate was determined as a function of O_2 and CO_2 concentrations and temperature. Temperature and atmosphere gaseous composition (O_2 and CO_2 concentrations) influenced the respiration rate of strawberry. Temperature had a higher impact on respiration rate than gaseous concentration. A 72–82% decrease in respiration rate was achieved when temperature was reduced from 23 to 10 °C for all gaseous mixtures studied. Higher O_2 concentrations increased the respiration rate at all temperatures, regardless of CO_2 concentrations.

The impact of equilibrium atmosphere packaging technology on improving quality attributes including pH, acidity, Brix, color, and texture profile analyses of fresh strawberries depends on the characteristics of the packaging material and the choice of appropriate quality parameters. In equilibrium modified packaging, atmosphere modifications depend on adjustment of the atmosphere inside the package, accomplished by the natural interaction between two processes, the respiration of the strawberries and the transfer of gases through the packaging, that prompts to an atmosphere richer in CO_2 and lower in O_2. Equilibrium-modified atmosphere packaging using various lid films was shown to maintain the initial quality of fresh strawberries for at least 10 days storage. Compared with the linear low-density polyethylene, cast polypropylene and polyethylene terephthalate/ethylene vinyl alcohol/polyethylene low acetyl fractions were much more successful in maintaining strawberry quality during storage. Reduction in packaging film permeability was accompanied by retention in the quality of strawberries (Caner et al. 2008).

Edible Coatings

The application of edible coatings has been extensively studied in strawberry shelf life enhancement (Tapia et al. 2008; Aday and Caner 2010). An edible coating consists of a thin layer which is formed directly on the surface of product as a protective

cover. These materials act as barriers that produce modified atmospheres, minimizing respiration rates, reducing moisture exchange, delaying deterioration, controlling microbial growth, and carrying functional ingredients like antioxidants, antimicrobials, and other preservatives (Geraldine et al. 2008; Aday and Caner 2010). Considering economical issues and functional advantages, fruits with high economic value and short postharvest life like strawberries are the main products benefitting from coating application.

Guerreiro et al. (2015) studied the effect of edible coatings based on sodium alginate and pectin enriched with essential oils on the shelf life extension of strawberries, and reported that coatings were effective in reducing microbial spoilage of fresh fruits and could be stored with good sensory properties for a period of 7 days. Edible active coatings based on pectin, pullulan, and chitosan incorporated with sodium benzoate and potassium sorbate were employed to improve the quality and shelf life of strawberries (Trevino-Garza et al. 2015). Edible active coatings based on polysaccharides improved the physicochemical, microbiological, and sensory characteristics, increasing the shelf life of strawberries from 6 (control) to 15 days (coated fruits) (Fig. 1).

Fan et al. (2009) developed a novel edible biofilm in which the fruit surface was covered with the microorganism *Cryptococcus laurentii* in combination with alginate, glycerol, palmitic acid, glycerol monostearate, and cyclodextrin. Edible alginate-based biofilms containing *C. laurentii* as an active compound acted as an antagonist and reduced microbiological decay, decreased weight loss, maintained the firmness of strawberries, and preserved the commercial quality of the fruit throughout the storage period of 20 days. Sogvar et al. (2016) studied the effects of an edible coating based on natural *Aloe vera* gel in combination with ascorbic acid at different concentrations on strawberry fruit and found that treatment may be a useful biochemical method to delay weight loss, had higher soluble solids content, vitamin C concentrations, and titratable acidity. The coatings reduced the population of total aerobic mesophilic organisms, yeasts, and molds during storage. To increase the shelf life of strawberries, the effect of edible films made of polymers like candelilla wax and beeswax were studied by researchers (Velickova et al. 2013; Oregel-Zamudio et al. 2017). Candelilla wax in combination with a biocontrol microorganism *Bacillus subtilis* HFC103 strain is a promising alternative to reduce postharvest deterioration of strawberry (Oregel-Zamudio et al. 2017). Chitosan and addition of beeswax as separate or composite coatings showed remarkable results. Chitosan-based coatings prolonged the storage period of strawberries for 7 days at a temperature of 20 °C and relative humidity of 53%. The coatings modified the respiration rates of the strawberries and slowed down their metabolism, as shown by the retention of the color and texture of the tissue (Velickova et al. 2013). Eshghi et al. (2014) developed a novel technique of using nanochitosan suspension (50–110 nm) at 4 ± 1 °C with 70 ± 5% relative humidity for 20 days. The nanochitosan-based edible coating improved the shelf life more than 2.5-fold compared with the uncoated samples. Sensory analysis of strawberries based on visual damage showed that nanochitosan coatings delayed fruit senescence associated with color changes, off-flavor development, and dehydration.

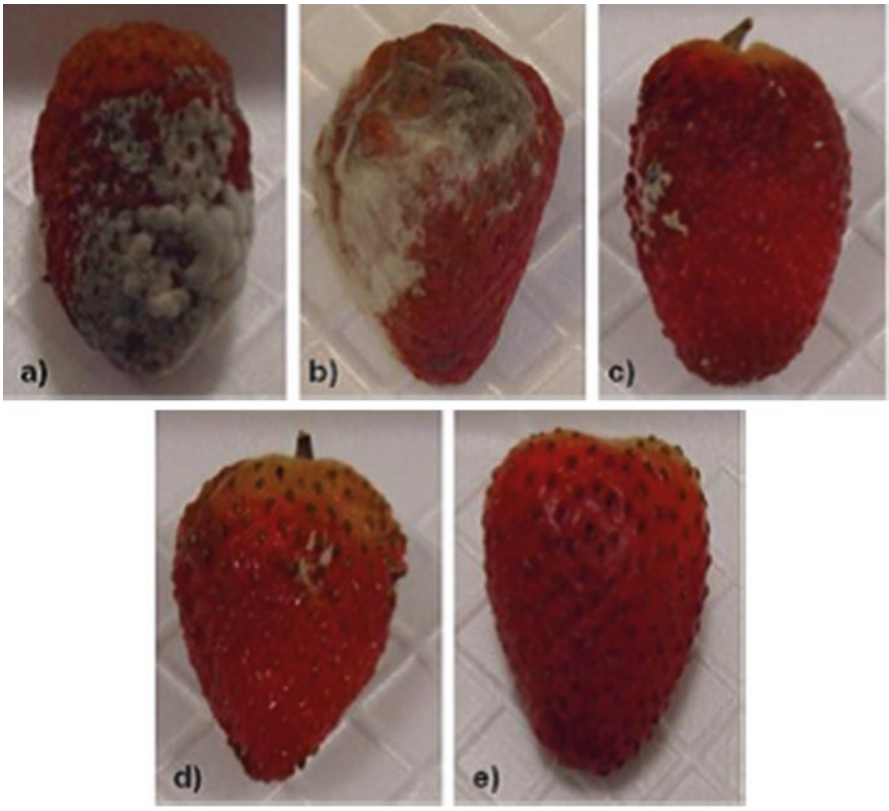

Fig. 1 Effect of edible coatings on the decay rate of strawberries stored at 4 °C for 15 days: (**a**) control, (**b**) antimicrobial treated, (**c**) pectin edible active coatings, (**d**) pullulan edible active coatings, (**e**) chitosan edible active coatings (Trevino-Garza et al. 2015)

Strawberries are highly prone to in-transit vibration damage causing skin abrasion and bruising. From these abrasions and bruises on the tissues of berries, microbes are able to enter, which, in turn, causes the degradation of berries and reduce the shelf life. Dhital et al. (2017) studied the impact of edible coatings for extending the shelf life of 'Chandler' variety subjected to simulated vibrations of local transportation. Curcumin and limonene were used as natural antimicrobials and coatings were set up from their liposomes and overcoated with methyl cellulose. Among different coating types, liposomes were found to be the most effective for the preservation of strawberry quality and the limonene liposome was observed to be effective in controlling fungal decay on strawberries for a prolonged period of storage. Pagliarulo et al. (2016) reported that peony extracts (*Paeonia rockii*) in chitosan coating was able to effectively slow the growth of the native fungal microflora on strawberries. The microbiological tests showed a high antifungal activity of the edible active coating at relatively low concentrations of peony extract.

Considering the remarkable effectiveness and security, edible coatings serve as a very promising tool for the shelf life enhancement of strawberries.

Gamma Irradiation

Processing by ionizing radiations such as gamma accelerated electron beams and X-ray has become an effective means of preserving fresh fruits (Fan et al. 2003). Food preservation by ionizing radiation, especially from cobalt-60 gamma sources and electron accelerators, has received much attention over the past few decades and detailed investigations have been undertaken into the possible use of this process for solving the problems encountered with fruits. Many investigations on this subject have been carried out and they established that the shelf life of fresh strawberries can be extended by postharvest irradiation treatments (Quaranta and Piccini 1984; Hussain et al. 2007).

Gamma irradiation treatments proved to be effective in reducing microorganisms in fresh strawberries, and an upper dose of 2.0 kGy was found to reduce fungal infections without affecting the quality of fruit (O'Connor and Mitchell 1991). Hussain et al. (2007) also confirmed that a gamma irradiation dose of 2.0 kGy was effective in delaying the mold growth and extending the storage life of strawberry by 8 days under refrigerated conditions. Also, a combination of carboxymethyl cellulose coating and irradiation at a dose of 2.0 kGy was found to be significantly effective in maintaining the quality, and delaying the decay and appearance of the mold growth for up to 18 days during refrigerated storage (Hussain et al. 2012). Hence, it can further facilitate the marketing of the strawberry fruit to distant markets. The efficacy of gamma irradiation on minimizing the decay of fruits may be associated to its ability of penetration deep into tissues and destroying spoilage microorganism harbored in wounds or inside host tissues, thus preventing or minimizing the decay process by inhibiting the growth of these microbes (Barkai-Golan 2001).

Vachon et al. (2003) studied the effect of gamma irradiation and various edible coatings on fresh strawberries. Their investigation showed that the gamma irradiation treatment and coating process were effective for reducing mold infections and, thus, extending the shelf life of fresh strawberries when stored at 4 ± 1 °C. Gamma irradiation of the strawberries at a mean dose of 1.5 kGy produced better results in terms of mold growth than coating the strawberries with a formulation based on calcium caseinate. The irradiation of the protein coating solution prior to the coating process of non-irradiated strawberries reduced the level of fruit contamination during the storage period compared to non-irradiated coating solution. However, no synergistic effect was observed when strawberries were irradiated at 1.5 kGy and coated with an irradiated caseinate-based formulation. The effect of low-dose gamma irradiation (1 kGy) and active equilibrium-modified atmosphere packaging on the quality of strawberries stored at 4 °C for 21 days was investigated by Jouki and Khazaei (2014). The results showed that the gamma irradiation protected straw-

berries from spoilage for up to 2 weeks in active equilibrium-modified atmosphere packaging at 4 °C without any attack of fungus or any change in their external appearance. It was concluded that low-dose gamma irradiation in combination with active equilibrium-modified atmosphere packaging will enable food processors to deliver larger amounts of high quality strawberry with extended shelf life. Studies have shown that strawberries treated with gamma irradiation exhibited higher antioxidant activity and less decay than controls (Maraei and Elsawy 2017). This behavior of phenolic compounds may be due to the destructive processes of oxidation and gamma radiation, which are able to break the chemical bonds of polyphenols, releasing soluble phenols with low molecular weight and increasing these compounds with antioxidant action (Adamo et al. 2004).

Methyl Jasmonate

Jasmonic acid and its methyl ester (methyl jasmonate) are cyclopentanone compounds and are regarded as naturally occurring plant growth regulators. Strawberries treated with methyl jasmonate in conjunction with ethanol showed higher antioxidant activity, total phenolics, and anthocyanins than those treated with ethanol or the controls (non-treated). The strawberry maintained an acceptable overall quality for the longest storage duration. Postharvest life was longer for those berries treated with methyl jasmonate–ethanol and methyl jasmonate than those treated with ethanol or control fruit (Ayala-Zavala et al. 2005). Mukkun and Singh (2009) studied the role of methyl jasmonate in strawberry cv. Pajaro fruit ripening by monitoring its endogenous concentration in fruit at various stages of development and the effects of exogenously applied methyl jasmonate at these stages on ethylene biosynthesis. Endogenous methyl jasmonate detected in fully ripe, half-ripe, and white 'Pajaro' strawberry fruit was trans-methyl jasmonate. The concentration of trans-methyl jasmonate in strawberry was significantly higher at the white stage (162 ng g^{-1}) and declined to 1.3 ng g^{-1} as the fruit developed to the fully ripe stage. Higher concentrations of endogenous methyl jasmonate in the white stage of strawberry fruit and its decline as the fruit ripens indicates that methyl jasmonate may play an important role in modulating fruit ripening. The ethylene production was highest when applied at 50 μM. It also increased the activities of 1-aminocyclopropane-1-carboxylic acid synthase and 1-aminocyclopropane-1-carboxylic acid oxidase, depending on the concentration of methyl jasmonate applied, as well as on the fruit developmental stage.

1-Methylcyclopropene

1-Methylcyclopropene (1-MCP) is a competitive inhibitor of ethylene action which binds to the ethylene receptor to regulate tissue responses to ethylene.1-MCP inhibits ethylene action in plants at very low concentrations and extends the life of fruits

(Jiang et al. 1999; Ku and Wills 1999). Jiang et al. (2001) treated strawberry (cv. Everest) with 1-MCP at various concentrations from 0 to 1000 nL/L at 20 °C for 2 h. 1-MCP treatment maintained strawberry firmness, color, and also reduced ethylene production. It delays fruit color and firmness that can be attributed to the decrease in ethylene production. However, disease resistance was decreased in fruits treated at high 1-MCP concentrations (500 and 1000 nL/L). Treatment with 1-MCP also inhibited phenylalanine ammonia-lyase activity, which is a key enzyme in the biosynthesis of phenolics (Cheng and Breen 1991), and decreased anthocyanins and phenolic compounds. The low levels of phenolics in the fruit treated at the highest concentration (i.e., 1000 nL/L) of 1-MCP could account for the reduced resistance to natural infection. Aguayo et al. (2006) reported that 1-MCP alone had no effect on firmness and appearance quality of fresh-cut strawberry fruit. However, 1-MCP had a synergistic effect in slowing down softening and deterioration rates when combined with a calcium chloride dip and controlled atmosphere storage at 3 kPa O_2 and 10 kPa CO_2.

Active Packaging

Active packaging can be outlined as a mode of packaging within which the package, the product, and the environment interact to extend shelf life or enhance safety or sensory properties, at the same time retaining the quality of the product (Suppakul et al. 2003). Active packaging involves setting absorbers inside the package (Guynot et al. 2003), and includes concepts such as oxygen and carbon dioxide scavenging and generation, and moisture regulation systems (Suppakul et al. 2003). Strawberries are known to be sensitive to humidity. Strawberry fruit can lose water during storage, which can be trapped within the headspace of the package and supports microbial growth and undesirable textural changes (Mahajan et al. 2008). Moisture-absorbing sachets containing silica gel can be utilized to control this problem. Aday and Caner (2011) assessed the potential effects of liquid chlorine dioxide, zeolite, and silica gel sachet systems combined with active packaging treatments in preserving the quality of fresh strawberries during storage at 4 °C. Chlorine dioxide treatments had a beneficial effect on firmness, total soluble solids, and color values. The minimum weight loss was obtained in strawberries with sachet treatments. Treatments delayed the senescence process, with resulting minimum CO_2 levels at the end of the storage. In another study, Aday et al. (2011) reported the effectiveness of carbon dioxide and oxygen scavengers to maintain the quality characteristics of fresh strawberries. The fruit was treated with oxygen and carbon dioxide scavengers throughout storage at 4 °C for 4 weeks. The use of active packaging resulted in slow accumulation of carbon dioxide and consumption of oxygen. The package headspace with CO_2 absorbers had the lowest CO_2 accumulation and O_2 absorbers resulted in constant O_2 levels throughout storage. The results showed that oxygen and carbon dioxide scavengers could be a feasible way for maintaining quality, controlling decay, and, therefore, extending the shelf life of strawberry.

Furthermore, active packaging could be used satisfactorily during the distribution and storage chain.

A novel nanopackaging material with lower relative humidity, oxygen transmission rate, and high longitudinal strength was synthesized by blending polyethylene with nanopowder. When used as a package for strawberries at 4 °C, it was able to maintain sensory, physicochemical, and physiological quality of strawberry fruits at a higher level compared with polyethylene bags (Yang et al. 2010). The result indicated that nanopacking displayed distinguished quality benefits appropriate to the preservation of fresh strawberry and will likely assist commercial producers and retailers in extending the shelf life of products over a broader range.

Postharvest Diseases and Disorders

Strawberries have a very limited shelf life due to their susceptibility to fungal decay, loss of firmness, loss of brightness and color darkening, mechanical injury, texture softening, physiological deterioration, and microbiological decay (Velde et al. 2013; Vu et al. 2011). A number of fungal species are known to cause postharvest diseases of strawberries, like gray mold rot, *Rhizopus* rot, and anthracnose. The latter two diseases are major problems at warmer temperatures, whereas the former usually develops under refrigerated conditions.

Gray mold rot caused by *Botrytis cinerea* is the most serious disease of strawberry fruits. The development of this disease during postharvest handling results from preharvest infections, while postharvest infections occur occasionally when healthy fruits are oppressed against the lesion of a diseased fruit. Control of *B. cinerea* is normally carried out by the regular application of fungicides (Wedge et al. 2007). Application of the biocontrol yeast *Rhodotorula glutinis* with salicylic acid provides a more effective control of postharvest gray spoilage and natural spoilage of strawberries (Zhang et al. 2010). Chitosan beads loaded with lavender essential oil can extend the mold-free storage life of strawberry stored at 7 °C from 2 days (control) to 8 days (Sangsuwan et al. 2016). Jin et al. (2017) found that UV-C treatment directly activated disease resistance against gray mold caused by *B. cinerea* in strawberry fruit.

Rhizopus rot caused by *Rhizopus stolonifer* is another severe postharvest disease of strawberries (Romanazzi et al. 2001). Protective fungicidal sprays are helpful for the control of rot. The combination of antagonistic yeast *Cryptococcus laurentii* and short hot water dips (at 55 °C for 30 s) could be an alternative to chemicals for the control of postharvest *Rhizopus* rot on strawberries (Zhang et al. 2007).

Anthracnose caused by either *Colletotrichum gloeosporioides*, *C. acutatum,* or *C. fragariae* is responsible for serious damage on foliar and fruiting plant parts, as well as for root necrosis (Freeman et al. 1998). Wedge et al. (2007) reported that cyprodinil + fludioxonil and azoxystrobin fungicide treatments were effective in reducing anthracnose in strawberries.

Conclusion

Strawberry is a highly perishable fruit with huge nutraceutical and commercial value. Thus, quality maintenance and shelf life enhancement of strawberry is very important. Harvesting at the proper stage of maturity is essential for optimum quality and, often, for the maintenance of this quality after harvest. There are many challenges concerning the safety and quality of strawberries which are faced during pre- and postharvest stages. The application of new technologies can help to maintain fruit quality, thereby extending their shelf life and decreasing the postharvest losses.

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Postharvest Biology and Technology of Berries

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Introduction

The word 'berry' has two meanings: one based on a botanical definition and the other on common commercial identification. True (botanical) berries are fleshy fruit with a cartilaginous endocarp full of seeds (Westwood 1993). The common term 'berry fruit' includes different fruits, such as blueberry (*Vaccinium* spp.), currant and gooseberry (*Ribes* spp.), and raspberry and blackberry (*Rubus* spp.). 'Berry fruit', 'soft fruit', and 'small fruit' are synonymous terms for the above-mentioned species, and they are used indifferently (Donno et al. 2013). Berries have been valuable as a food source for humans since before the start of agriculture, and remain among the primary food sources of other primates (Kiple et al. 2000). They were a seasonal staple for early hunter-gatherers for thousands of years and, today, wild berries gathering remains a popular activity in Europe and North America and have been an important part of the diet of indigenous people. Berries are usually juicy, rounded, bright-colored, sweet or sour, and do not have a stone or pit, although many pips or seeds may be present. Small berries represent a very diverse group, including a variety of red, blue, or purple small-sized and highly perishable fruits (Manganaris et al. 2014). The most economically important and best described berry crops include blueberry, cranberry, currant (black, red, or white), gooseberry, blackberry, raspberry (black or red), and others of minor economic importance (i.e., boysenberry, bilberry, jostaberry, cloudberry, loganberry, lingonberry). Berries are highly appreciated for their sharp color, delicate texture, and unique flavor. Despite having a number of common attributes, the group is quite diverse and comprises

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Table 1 Area and production of various small berries around the world

S. no.	Small berries	Area (ha)	Production (tons)	Largest producer (tons)
1.	Blueberries	95,195	525,620	USA (262,539)
2.	Raspberries	93,229	612,571	Russia (144,000)
3.	Currants	117,440	659,026	Russia (372,000)
4.	Gooseberries	30,744	170,584	Germany (88,191)
5.	Cranberries	56,496	652,261	USA (381,018)

Source: FAOSTAT (2014)

simple (e.g., blueberry, cranberry) and composite fruits derived from single or multiple fused fertilized ovaries (e.g., strawberry, mulberry, raspberry, blackberry). Small berry fruits are consumed fresh because of their attractive color, special taste, and are considered one of the richest sources of natural antioxidants (Manganaris et al. 2014). However, berries have a short storage life, as a result of their high respiration, softening rate, and susceptibility to mechanical damages and decay. As berries are considered non-climacteric fruit, they must be harvested at or near to full maturity, because they will not continue to ripen normally once detached. At this stage, the fruit presents appropriate organoleptic attributes but may become softer and more sensitive to mechanical damage. Thus, it is crucial to be extremely careful during harvest and postharvest handling and to sort, grade, and pack the berries in the field, avoiding excessive manipulation of the fruit (Horvitz 2017). According to the FAO database 2014, the total area and production of various berries is given in Table 1.

Importance

Berries represent an important source of micro- and macronutrients, including fiber, sugars, vitamins, minerals, etc.; however, most of their health-promoting properties have been associated largely with their high levels of bioactive compounds (namely, ascorbic acid, phenolic acids, and flavonoids, including anthocyanins) with known antioxidant capacity. Berries contain a number of antioxidants, such as ascorbic acid, phenolics, ellagic acid, ellagitannins, and flavonoids, including anthocyanins (Rommel and Wrolstad 1993; Clifford and Scalbert 2000). They have a high antioxidant effect against reactive oxygen species (ROS) produced in the human body (Kahkonen et al. 2001; Mullen et al. 2002). In general, they are rich in sugars (glucose, fructose) but low in calories. They contain only small amounts of fat but a high content of dietary fiber (cellulose, hemicellulose, pectin); organic acids, such as citric acid, malic acid, tartaric, oxalic, and fumaric acid; certain minerals in trace amounts, some vitamins (ascorbic acid and folic acid); and phytochemicals, such as phenolic compounds (Kowalenko 2005; Nile and Park 2014). The nutritive value of berries is presented in Table 2.

Table 2 Nutritional composition of important temperate berries

Nutrient	Value per 100 g					
	Blueberry	Cranberry	Blackberry	Raspberry	Current	Gooseberry
Energy	57 kcal	46 kcal	43 kcal	52 kcal	63 kcal	44 kcal
Protein	0.74 g	0.4 g	1.39 g	1.20 g	1.4 g	0.88 g
Fat	0.33 g	0.13 g	0.49 g	0.65 g	0.41 g	0.58 g
Carbohydrate	14.49 g	12.2 g	9.61 g	11.94 g	15.38 g	10.18 g
Fiber	2.4 g	4.6 g	5.3 g	6.5 g	4.3 g	4.3 g
Sugars	9.96 g	12.10 g	7.70 g	–	–	–
Calcium	6 mg	8 mg	29 mg	25 mg	55 mg	25 mg
Iron	0.28 mg	0.25 mg	0.62 mg	0.69 mg	1.54 mg	0.31 mg
Magnesium	6 mg	6 mg	20 mg	22 mg	24 mg	10 mg
Phosphorus	12 mg	13 mg	12 mg	–	59 mg	27 mg
Potassium	77 mg	85 mg	0.62 mg	151 mg	322 mg	198 mg
Sodium	1 mg	2 mg	1 mg	1 mg	2 mg	1 mg
Vitamin C	9.7 mg	13.3 mg	21 mg	26.2 mg	181 mg	27.7 mg
Thiamine	0.037 mg	0.012 mg	0.020 mg	–	0.050 mg	0.040 mg
Riboflavin	0.041 mg	0.020 mg	0.018 mg	0.038 mg	0.050 mg	0.030 mg
Niacin	0.418 mg	0.101 mg	0.646 mg	0.598 mg	0.300 mg	0.300 mg
Vitamin A	54 IU	60 IU	214 IU	33 IU	230 IU	290 IU
Vitamin E	0.57 mg	1.20 mg	1.17 mg	1.42 mg	–	0.37 mg
Vitamin K	19.3 µg	5.1 µg	19.8 µg	7.8 µg	–	–

Source: USDA National Nutrient Database (www.nutrition-and-you.com)

The main pigments responsible for the color of blueberries, raspberries, and blackberries are anthocyanins. Anthocyanins may be localized in the skin or in the entire fruit and are largely responsible for fruit color, although small amounts of carotenoids are also present. The total anthocyanin content of blueberry cultivars ranged from 57 to 208 absorbance units/g fresh weight at harvest (Perkins-Veazie et al. 1995).

Blueberries and Cranberries

Blueberry fruit comprises of lowbush blueberry (*Vaccinium angustifolium*), highbush blueberry (*Vaccinium corymbosum*), bilberry (*Vaccinium myrtillus*) and rabbiteye blueberries (*V. ashei* Reade). On the other hand, cranberry fruits include two major species, viz., *Vaccinium macrocarpon* and *Vaccinium oxycoccos*. The genus *Vaccinium* involves over 400 species, which belong to the Ericaceae (heath family). These are the most commercially grown species in temperate countries. These berries are rich in anthocyanins, have strong antioxidant property, and are considered as functional foods. They are also moderately acidic and less sweet, and, hence, ideal for the diabetic population. The berries are very fragile and do not store

very well for long periods. The ripe berries are harvested and, ideally, they can be frozen to preserve the nutrients as soon as they are picked. The fruits are processed into juice, sauce, fruit-flavored pieces, etc. Just like blueberry and bilberry, cranberries are very rich in anthocyanins and proanthocyanidins. They are strong antioxidants, as well as help to prevent urinary tract infections (Cho et al. 2004; Kalt et al. 2007; Rimando et al. 2005). Both blueberry and cranberry are native to North America and they are well known for containing bioactive compounds that can benefit human health. Generally, blueberries are regarded as one of the richest sources of antioxidants of all fresh fruits and vegetables (Prior et al. 1998). Compared with other fruits, canned blueberries are also a good source of iron, a fair source of vitamin A, and an average in terms of protein, fat, carbohydrate, calories, and calcium content. In addition, fresh blueberries and cranberries are a fair source of vitamin C (Galletta and Ballington 1996).

Blackberries and Raspberries

Rubus is a broad genus of flowering plants in the family Rosaceae (Bailey 1949), subfamily Rosoideae. The *Rubus* species are collectively referred to as 'brambles' in the eastern USA, as 'caneberries' in the western USA, and include blackberries, dewberries, and raspberries. The genus *Rubus* is prominent in North America, comprising more than 400 species (Bailey 1949). Blackberries (*Rubus* sp. L.), red raspberries (*R. idaeus*), and black raspberries (*R. occidentalis* L.) are commercially grown species of the genus *Rubus*. They are found worldwide, except in desert areas, but present mainly in the northern hemisphere (Mertz et al. 2009). Blackberries and red raspberries are sold fresh, primarily in clam shell packages and as processed products, whereas the bulk of the black raspberry crop is processed. Blackberry fruit, for instance, tend to be first green and red to brown-red and hard when immature, but turn into black-colored and juicy fruit as they ripen. Most of the commercial blackberry production occurs in the USA, but appreciable amounts are also grown in the UK and New Zealand (Dai et al. 2007). Blackberries are considered to be promising sources of active compounds, with neuroprotection qualities against age-related diseases, such as neurodegeneration. Among the berry species, raspberries have similar content to strawberries and blackberries, about three times more ascorbate than blueberries, but less than in red currants, and several times less than the blackcurrant vitamin content (Kalt et al. 1999; Benvenuti et al. 2004).

Currant and Gooseberries

The genus *Ribes* embraces the shrubs of both currants and gooseberries and belongs to the family Saxifragaceae. It includes more than 150 described species of bushes that are native throughout Northern Europe, North America, Asia, and in

mountainous areas of north-west Africa and South America (Brennan 2005). Five main *Ribes* subgenera are grown for their fruit and these include blackcurrants, redcurrants, whitecurrants, gooseberries, and jostaberries (Brennan 2005). Besides the high content of tasty juice, blackcurrant is a valuable source of bioactive compounds like vitamin C and polyphenols, acting as antioxidants with a potential to protect against disorders such as cardiovascular events, cancer, and other degenerative symptoms.

Postharvest Biology of Berries

Small berry fruits are very diverse in their morphological and compositional features, postharvest physiology, and in most favorable postharvest necessities and recommendations. Based on perishability, these berries are grouped under highly perishable food commodities. However, all these fruits are characterized by high water content and potential for water loss, resulting in shriveling, susceptibility to mechanical injury, and susceptibility to attacks by microorganisms (bacteria, fungi) and insect infestation. Fresh berry fruits are living organs subject to continuous changes after harvest, and, therefore, attention to detail is required throughout the handling system between the sites of production and consumption. Some of the changes that occur after harvest in these fruits are desirable and may require specific treatments and techniques to promote them, while many other changes are undesirable and require treatments and techniques to delay and minimize their incidence and severity. Although none of the changes in fresh fruits can be stopped, many can be retarded. Ripening and senescence, the last stages in the development of fresh berry fruits, are characterized by some irreversible processes that lead to breakdown and death of the fruit. Understanding the biological and environmental factors affecting the postharvest deterioration rate is essential to developing treatments for maintaining quality and extending postharvest life.

Fruit Growth and Development

Fruit growth involves various degrees of cell division and cell expansion. During fruit set, when a flower has been successfully pollinated (exceptionality in parthenocarpic fruits), the fruit becomes an active carbohydrate sink and many of its tissues become meristematic. In addition, the hydrolysis of sucrose into glucose and fructose is also intensified during fruit ripening. Fructose is the predominant sugar present in berries. In fruits like currants and blackberries, cell divisions are completed by the time of pollination (Monselise 1986).

Fruit Maturation and Ripening

Maturation refers to the processes that lead to ripening and, in many cases, maturation and ripening overlap in time (Giovannoni 2001). Fruit ripening is a highly coordinated, genetically programmed process occurring at the later stages of maturation and involves a series of physiological, biochemical, and sensory changes, leading to the development of an edible ripe fruit with desirable quality parameters (Brady 1987). Specific biochemical and physiological changes vary among species, although they include altered sugar metabolism, softening, color changes, synthesis of aroma volatiles, and increased susceptibility to pathogen infection, suggesting that the underlying genetic mechanisms that regulate fruit ripening are well conserved between fruits of different species (Adams-Phillips et al. 2004; Giovannoni 2004). The small berries also have citric acid as a predominant organic acid. However, chlorophyll degradation and synthesis of pigments such as anthocyanins and carotenoids are also ethylene-dependent processes, even in non-climacteric fruit berries. Increase in fresh weight, tissue softening, changes in soluble solids, titratable acidity, and color changes during maturation and ripening are common phenomena in berry fruits (Castrejón et al. 2008). Fruit weight is an important character, which starts increasing quickly after the commencement of maturation and ripening. The highest increase in weight occurred in unripe berries until reaching the ripening stage. This increase is, on average, more than double (56%) that of the unripe green berries. After reaching horticultural maturity and throughout successive harvest, all cultivars decreased in average weight around 12%, whereas soluble solids increased from 9 to 15% from the unripe to the ripe fruit stages, respectively. Meanwhile, titratable acidity was reduced to approximately 78% (Castrejón et al. 2008). Blueberry fruit exhibits a double sigmoidal curve in weight increase (Tamada 2004). The maturity stages selected for this study represented more the second growth period of blueberry fruit, which leads to ripe fruits. In respect to the total phenol content, after unripe green berries stage, the total phenolic content decreased during color break and ripening, particularly at the unripe purple berries stage. At ripening, the total phenolic content ranged from 21.36 (green unripe berries) to 15.13 (ripe blue) mg GAE/g DM. The major phenol component involves the hydroxycinnamic acids, followed by total anthocyanin at the ripe berry stage (Castrejón et al. 2008), whereas it is almost absent at the unripe green berry stage (Kalt et al. 2003). The fruit growth curve in cranberry is reported to be a single sigmoid curve (Chandler 1952). The cranberry is a non-climacteric fruit, because there is no climacteric peak near maturity (Abdallah and Palta 1989). The fruit growth and development starts after fruit set. The fruit weight increases by 12% from the date of first harvest to the date of the optimum harvest date. The size and number of seeds have major roles in the development of berry (Rigby and Dana 1971). In respect to the respiration rate and ethylene production rate, the maximum rate is found at the earlier green stage of fruit growth, which grows rapidly thereafter and becomes steady at maturity. The commercial value of cranberry depends on the attractive red color, which is due to anthocyanin pigments.

Compositional Changes During Ripening

The characteristics and composition of ripe fruit are the result of biochemical and physiological changes. Harvesting of berries should be at near the full ripeness stage, or the maximum ripeness stage that can be safely distributed to market to maximize sweetness and flavor development, as berries do not accumulate starch during development and, therefore, do not increase in soluble solids (an estimate of sugar content) after harvest (Zhao 2007). Titratable acidity, largely made up of citric acid in most berries, often decreases as the fruit ripens and after harvest. This decrease can enhance the perceived sweetness of berries or result in bland flavor, if the final concentrations are too low (Perkins-Veazie and Nonnecke 1992). As blueberries develop and ripen, there is an increase in soluble solids and decrease in overall titratable acidity. Ripe berries will remain attached for several days to weeks and sugars will continue to accumulate. Blueberries exhibit increases in malic, chlorogenic, and phosphoric acid, and decreases in citric and quinic acids during ripening. The amount of citric acid in blueberries varies with the variety. The soluble solids content of blueberry cultivar soluble solids content ranged from 9 to 11.5% and titratable acidity from 0.54 to 1.13 citric acid equivalents, resulting in a soluble solids:titratable acidity ratio ranging from 10 to 19 among the ten cultivars tested at harvest. Raspberries also increase in soluble solids and decrease in titratable acidity as they develop and ripen. Titratable acidity, soluble solids, pH, and acidity vary greatly between cultivars. Blackberries increase in soluble solids content and decrease in titratable acidity during ripening on the plant (Perkins-Veazie and Nonnecke 1992).The increase in soluble solids occurs particularly between the 50% black and shiny black stage, and increases also due to weight loss during storage (Walsh et al. 1983). There are greater changes in titratable acidity than soluble solids as ripening progresses. Titratable acidity in blackberry decreased sharply between the mottled and shiny black ripeness stages, depending on the cultivar (Perkins-Veazie et al. 1996). Following storage, titratable acidity decreases 10–30%, depending on the stage of harvest. Sometimes, titratable acidity increases in very ripe fruit due to weight loss in storage. Blackberries can develop a red discoloration after harvest. This is theorized to result from the harvesting of less mature fruit, resulting in less total pigment and a lower pH or differences in the relative concentration of various pigments (Perkins-Veazie et al. 1996). Berry fruits soften as they ripen. Fruit firmness in raspberries was shown to be influenced by overall fruit size, hairiness, number and size of drupelets, and receptacle cavity size. Extensive fruit softening occurred with the transition in blueberry color from red to blue-red.

Harvesting and Maturity Indices

To get the maximum quality at harvest and maintain this quality during transport and commercialization until the fruit is consumed, it is essential to harvest berries at the optimum stage of maturity (Sturm et al. 2003). In order to avoid excessive

manipulation and damage to the fruit, berries for the fresh market should be hand-harvested, sorted, graded, and packed in the field, directly into the final container. Fruit ripeness at harvest and fruit handling are two critical factors in the postharvest keeping quality. In fact, the stage of maturity at harvest largely affects the shelf life of berries, their storage behavior, and sales probability (Krüger et al. 2003). The harvesting of blueberries, blackberries, and raspberries is determined by color development (Zhao 2007). Fruit should be harvested with full or nearly full color development to maximize eating quality. Berries should also easily detach from the plant when ripe. Because fruit ripens on the plant at different times, it must be harvested at intervals of a few days, depending on the weather, to prevent it from over-ripening (Mitcham et al. 1998).

Postharvest Losses

Raspberries are non-climacteric fruit, highly perishable for being susceptible to mechanical injury during transportation and picking, water loss, molds, and rots growing during storage. Mold growth limits the shelf life of fruits (Kim and Wills 1998; Hertog et al. 1999). During the growth stages of raspberry, physiological decay occurs due to the high respiration rates. For all these reasons, the postharvest life of red raspberries is limited to a few days (3–5 days) and only a small percentage of these fruits can be consumed fresh. Caneberries, which include blackberries and raspberries, must be picked when the berries are ripe or nearly ripe to ensure better quality. Their thin fruit skin, high respiration rate, and high ethylene production make these berries extremely susceptible to postharvest losses. Although both raspberries and blackberries are considered ‘soft’ fruits, raspberries are slightly more perishable in nature. The raspberry fruit is susceptible to greater moisture loss and fungal infection because of its lack of an outer protective covering (cuticle) and the fact that the raspberry fruit is left with a cavity in the center when detached from the plant (Samtani and Kushad 2015).

Postharvest Shelf Life

Fresh berries are highly perishable and their quality and shelf life can be greatly affected by different pre- and postharvest factors. A number of studies have reported the effect of preharvest factors, including climatic conditions and cultural practices, on different phenolic compounds and antioxidant values at harvest, and also on the shelf life during storage (Perkins-Veazie and Kalt 2002; Anttonen and Karjalainen 2005). Light and average temperature during fruit growth have a strong effect on the chemical composition and antioxidants of berry fruits (Lee and Kader 2000; Zheng and Wang 2001; Anttonen and Karjalainen 2005). The amount and extent of low and high temperatures during the growth and maturation periods of raspberries and

blackberries have a major influence on the antioxidants, including anthocyanins, vitamin C, and total phenolics (Rommel and Wrolstad 1993; Perkins-Veazie and Kalt 2002). Berries grown with lower light intensities and shorter day lengths have lower levels of sugars and antioxidants (Zheng and Wang 2001). Fruiting order has also been shown to have a significant effect on phenolics content in strawberry and the phenolics content generally increases from primary to tertiary fruits. Tertiary fruits have been reported to contain 10, 25, and 11% higher amounts of total phenolics, ellagic acid, and antioxidant capacity, respectively, than primary fruits. The effects of storage on the contents of anthocyanins, ellagic acid, and vitamin C in raspberries have been investigated (Mullen et al. 2002). A number of authors have noted that storage at low temperatures (2 °C) positively affects the quality and shelf life of fruit, including blueberries, blackberries, raspberries (Reynoso and De Michelis 1994), and strawberries (Pelayo et al. 2003). For growers and distribution chains, extending their growing season and increasing the shelf life of berries would be profitable. The shelf life of berries is shortened by numerous factors, including physical damage during harvest and handling, shriveling from moisture loss, fungal rot, and deterioration due to physiological factors (Samtani and Kushad 2015).

Factors Affecting Deterioration of Postharvest Fruit Quality

Respiration Rate

Bergman (1929) reported a definite increase in the respiration rate at the pink to red-ripe stage of the highbush blueberry, whereas developing fruits of the lowbush berry showed a gradual decline in the rate of respiration as the fruits matured (Hall and Forsyth 1967). Raspberries and blackberries are some of the most perishable fruits of berry crop, with very high respiration rates. Blueberries, cranberries, currants, and strawberries have lower respiration rates and longer storage life. Ethylene production is generally low for this group of fruit and many are non-climacteric. Postharvest physiologists and food technologists do not have many options to interfere with the respiratory process of harvested commodities, since they are largely dependent on the product-specific characteristics. The declining rate of respiration as fruit ripen from green to dark red suggests that raspberry fruit are non-climacteric (Perkins-Veazie and Nonnecke 1992); Biale and Young 1981). The respiration rate for red ‘Heritage’ fruit was lower than that reported for ‘Chilcotin’, ‘Meeker’, or ‘Willamette’ fruit (Robbins et al. 1989a, b). This difference may be due to the alleviation of water stress in harvested ‘Heritage’ fruit. The respiration rates of the receptacle tissue from mottled and pink fruits were higher than those of intact fruits. Receptacle tissue from red and dark red fruits had respiration rates similar to those of intact fruits and drupes (Perkins-Veazie and Nonnecke 1992). The ethylene (C_2H_4) production rates were low (3–8 μL kg^{-1} h^{-1}) for intact fruits and drupes, but were 40 times higher for detached receptacle tissues (Perkins-Veazie and Nonnecke 1992). It is well known that respiration rate is a sensitive physiological indicator of

mechanical stress or wounding in both vegetative tissues and fruits, with production being linearly correlated with the number of impacts and the increasing loads in blueberries (Burton and Schulte-Pason 1987). The high CO_2 production was also correlated with the percentage of fruit decay. Another indirect indicator of damage is weight loss. The increased weight loss in damaged fruits is perhaps due to changes in their biophysical properties: modification of cellular arrangements and tissue permeability, occurrence of small fissures connecting the fruit internal and external atmospheres (which would accelerate gas transfer, particularly water vapor), and increased respiration rate.

Ethylene Evolution Rate

Ethylene production is generally low for this group of fruits and many are non-climacteric (Zhao 2007). Ethylene accelerates abscission and pigment changes in raspberry and blackberry fruit (Burdon and Sexton 1990, 1993). Ethylene production of intact fruit was low in green and yellow fruit, higher during the transitions to mottled and pink stages, and similar to pink fruit during the transitions to red and dark red stages (Perkins-Veazie and Nonnecke 1992). Burden and Sexton (1990) detected low levels of ethylene production at the green and yellow stages of ripening in 'Glen Clova' raspberry fruit, but production increased greatly at the mottled and later stages of ripening. Rates of CO_2 and C_2H_4 production were highest in receptacle tissue and similar for intact fruit and drupes (Perkins-Veazie and Nonnecke 1992). Burden and Sexton (1990) have suggested that C_2H_4 produced in raspberry receptacle tissue accelerates formation of the abscission zone. Ethylene-forming enzyme activity can be limited by the supply of 1-aminocyclopropane-1-carboxylic acid or by the stage of ripeness (Cameron et al. 1979) and was measurable at the green stage (Perkins-Veazie and Nonnecke 1992). Activity was high in yellow fruit, low in mottled fruit, and increased during ripening. The effect was more pronounced in receptacle than in drupe tissue. Ethylene accelerates abscission zone formation (Burden and Sexton 1990) and promotes softening in raspberries (Robbins et al. 1989a, b). Exogenous ethylene has been shown to induce softening and color formation in raspberry (Burdon and Sexton 1990).

Compositional Changes

Compositional changes that occur during fruit ripening affect both the organoleptic and nutritional quality of small fruit. Understanding these developmental changes may aid in the optimization of fruit quality (Forney et al. 2012). The small temperate berry fruits contain major anthocyanins and these are essential in different processes that contribute to color, flavor, human nutrition, and health (Yahia and Ornelas-Paz 2010). During development and maturation of the fruit, numerous

changes occur in pigments. Loss of chlorophyll (green color) is desirable in berry fruits. The development of preferred red/purple/bluish color in berries is due to anthocyanins; these water-soluble pigments are much less stable than carotenoids (Kader 2002). In blueberry fruit, once ripening is initiated, fruit color changes rapidly on the plant, going from 50% pink to fully blue in 2–3 days (Forney 2009). This is accompanied by substantial increases in anthocyanin pigment concentration as the fruit changes from white to dark blue in blueberries (Kalt et al. 2003) or white to red in cranberries (Forney 2009; Vvedenskaya and Vorsa 2004). Similarly, the compositional changes in blueberry and cranberry fruit during ripening were successfully investigated by Forney et al. (2012). In blueberry fruit, the primary sugars are glucose and fructose, which increase from about 2–6% as fruit ripens from white to blue. The major organic acid is citric acid, which comprises 60–80% of the total organic acids in blueberries and declines by 60% as fruit ripens from white to blue. The total phenolics in blueberry fruit are 60% less than in white fruit and 12% less than in blue fruit, whereas anthocyanins increase as color develops. The antioxidant capacity declines from white to turning stages of fruit ripening. Fruit firmness decreases about 80% as fruit ripens from white to blue. The degree of compositional changes of cranberry fruit does not alter as much as blueberries during ripening. Sugar concentration increases from about 2.2–3.2% as fruit ripens from white to red, with glucose comprising 82–74% of the total sugars, respectively. But, at the same time, the acid content decreases by only 22%. Citric acid comprises over 50% of the acids in white cranberry fruit and declines to about 30% as the fruit transitions to the ripening stage. Similar to blueberries, the total anthocyanins increase as color develops and the total phenolics and antioxidant capacity remains relatively steady. In contrast to blueberries, red cranberry fruit were firmer than white fruit.

Temperature and CO_2

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. Fruits such as blueberries (Kalt and McDonald 1996) have shown high anthocyanin contents at low-temperature storage. A decline in ascorbate content was found in raspberries and lowbush blueberries during storage from 0 to 10, 20, and 30 °C (Kalt et al. 1999). Connor et al. (2002) noticed an increase in antioxidant activity in blueberry during cold storage. Higher antioxidant activity was directly related to the anthocyanin and phenolic contents of blueberry during storage. In contrast, no difference in antioxidant capacity was found in fresh, frozen, and cold-stored raspberries (Mullen et al. 2002). The effect of carbon dioxide partial pressure on blueberry fruit on respiration and respiratory quotient was studied by Beaudry (1993), who reported that high levels of CO_2 can reduce respiration significantly in blueberry.

Pathogens Attack

Postharvest decay is a common cause of deterioration in berry fruit. *Botrytis cinerea* is one of the most common pathogens observed after harvest. In many fruits, such postharvest decay results, in a large part, from preharvest quiescent infections (Sommer 1985). Other infections occur as a result of nesting; spreading of infections from fruit to fruit. All berry fruits have tender skins and raspberry has a very fragile structure because of the open receptacle cavity that is easily injured, allowing invasion by pathogens. Blueberry cultivars vary in their susceptibility to postharvest decay (Smith et al. 1996). *Colletotrichum acutatum*, *Colletotrichum gloeosporioides*, and *B. cinerea* are the main rots observed. In general, late-season berries were more susceptible to decay than fruit from earlier harvests. *Rhizopus* rot spores are present in the air and easily spread. The fungus will not grow at temperatures lower than 5 °C, and temperature management is the simplest method of control. However, the common pathogen *B. cinerea* continues to grow slowly at 0 °C in berries.

Postharvest Handling and Technology

Cold Storage

Cold storage, where only temperature and relative humidity are controlled in the storage chamber, is one of the main methods for the conservation of fruit quality parameters (Chitarra and Chitarra 2005). Thus, the reduction of temperature, up to a certain limit, increases the quality maintenance and extends the period of fruit supply to the consumer market. Recommended 0–2 °C temperature and 90–98% RH for temperate fruits and berries.

Hot Water Treatment

Blueberries undergoing hot water treatments (45, 50, or 60 °C) for 15 or 30 s led to significant increases in the headspace concentrations of a wide range of volatiles, the most important being ethanol, ethyl acetate, and ethyl 2-methylbutanoate, which are considered stress-induced volatiles (Fan et al. 2008).

Controlled Atmospheric Storage

Controlled atmosphere (CA) storage is a system for holding produce in an atmosphere that differs substantially from normal air with respect to CO_2 and O_2 levels. Controlled atmosphere storage refers to the constant monitoring and adjustment of

the CO_2 and O_2 levels within gas-tight stores or containers. The gas mixture will constantly change due to the metabolic activity of the respiring fruits in the store and leakage of gases through the doors and walls. The gases are, therefore, measured periodically and adjusted to the predetermined level by the introduction of fresh air or nitrogen or removal of CO_2.

Some success was reported by Washington State University in the USA around 1903, and subsequently by others, on controlled atmosphere storage of raspberries, blackberries, strawberries, and loganberries. Controlled atmosphere storage has continued to be used on an increasing scale, with an increasing variety of fruits, and with an increasing number of countries since that time. Raspberries are relatively tolerant to high CO_2. The recommended controlled atmosphere storage conditions for raspberry fruit are 15–20% CO_2 and 5–10% O_2(Kader 2001). The 'Heritage' raspberry fruit is non-climacteric (Perkins-Veazie and Nonnecke 1992); therefore, the fruit does not have a burst of CO_2 output during its postharvest life. This helps to explain why the CO_2 concentration did not accumulate to a high level inside the containers. The antioxidant activities of air-stored cranberries increased by 50% from their harvest levels in 2 months, while CA-stored fruits (21% O_2 + 30% CO_2) prevented this increase (Gunes et al. 2002). This may result from an impediment in the release of bound phytochemicals during the CA storage, which contribute to antioxidant activity. However, one study reported that apples stored in cold or controlled atmosphere did not show any effect of storage on antioxidant activity (Sluis et al. 2001). An increase in antioxidant activity during storage has been observed in apples stored in CA (2% CO_2 + 2% O_2) or cold storage for 4 months (Leja et al. 2003).

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is a technique used for prolonging the shelf life of fresh or minimally processed foods. In this preservation technique, the air surrounding the food in the package is changed to another composition. MAP is used with various types of products, where the mixture of gases in the package depends on the type of product, packaging materials, and storage temperature. However, fruits and vegetables are respiring products where the interaction of the packaging material with the product is important. If the permeability (for O_2 and CO_2) of the packaging film is adapted to the product respiration, an equilibrium-modified atmosphere will establish in the package and the shelf life of the product will increase (Sandhya 2010).MAP may provide suitable atmospheres to extend the shelf life of raspberries. Joles et al. (1994) recommended that raspberries can be stored at O_2 levels above 4 kPa at 0 °C, 6 kPa at 10 °C, and 8 kPa at 20 °C. Steady-state CO_2 partial pressures of 3–17 kPa had little or no effect on O_2 uptake or headspace ethanol partial pressures at 20 °C. Exposing raspberries to CO_2 levels of 20% or greater has been shown to delay gray mold decay and extend shelf life (Goulart et al. 1992). Elevated CO_2 has also been shown to improve the firmness of

strawberries (Smith 1992). It has been reported that an atmosphere of ≈20 kPa CO_2retards molds and extends the shelf life of raspberries (Goulart et al. 1992). Mold development was retarded for at least 1 day in packages with CO_2 partial pressures >15 kPa (data not shown). However, using LDPE film, O_2 levels at these CO_2 partial pressures caused fermentation (Joles et al. 1994). Ceponis and Cappellini (1983) and Smittle and Miller (1988) have shown that storing blueberries in a CO_2-enriched atmosphere is a fairly effective way to inhibit postharvest decay without fungicidal treatment. Therefore, MAP can possibly serve as an alternative to fungicides to extend the shelf life of fresh blueberries.

Innovative Packaging Technologies

During storage, a possibility to control the decreased quality would rely on packaging technologies able to modify the gas composition inside the package, slowing down the fruit metabolism and microbial growth. In fact, it is well known that $O_2$and CO_2 concentrations around 10% and 10–20%, respectively, are desirable to preserve the quality of fresh raspberries (Joles et al. 1994). To obtain this proper gas composition, modification of the atmosphere can be achieved through passive or active solutions (Brody et al. 2010). In the first case, the permeability of the packaging material and its selectivity towards gasses can be combined with the fruit metabolism to control the equilibrium of oxygen and carbon dioxide in the headspace around the product. In the second case, an active device quickly modifies the gas composition inside the packaging by releasing or absorbing oxygen and carbon dioxide.

Edible Coatings

Edible coatings are traditionally used to improve food appearance and conservation due to their environmentally friendly nature, since they are obtained from both animal and vegetable or agricultural products (Petersen et al. 1999). In general, coatings act as barriers to moisture and oxygen during processing, handling, and storage, and not only retard food deterioration, but also improve safety, due to their natural biocide activity or incorporation of antimicrobial compounds (Cha and Chinnan 2004). In general, the raspberry fruits treated with Aloe vera gel maintain higher antioxidant capacity, enzyme activity, and less decay. Aloe vera gel coating could be a valuable non-chemical way of maintaining raspberry fruit quality and extending their postharvest life (Hassanpour 2015).

Chemical Treatments

Calcium Chloride

The quality of small berries declines rapidly after harvest and storage life may be less than a week (Wills 1998). This problem may be overcome with calcium chloride application (Astuti et al. 2013). The involvement of Ca in the regulation of fruit ripening is well established (Aghdam et al. 2012). Calcium contributes to improving the rigidity of cell walls, retards tissue softening, and also reduces the accessibility of cell wall-degrading enzymes to their substrates (Vicente et al. 2009). Moreover, calcium is considered to be an important mineral element that regulates fruit quality, specifically, the maintenance of fruit firmness (Lurie 2009).The berry fruits (blackberry, raspberry, and strawberry) treated with calcium (1 and 2%) by immersion increased their ascorbic acid content. The total phenolics content and antioxidant potential in stored fruit is higher if treated with calcium chloride. Calcium chloride treatment also has a positive effect on the retaining process of monomeric anthocyanins during storage. Calcium chloride dip is a practical way to extend the shelf life and nutritional quality of blackberries, raspberries, and strawberries during chilled storage (Turmanidze et al. 2016). Exogenous application of calcium chloride 0.25–0.50% at harvest significantly enhances berry firmness and reduces ethylene levels in raspberry. In berries, the use of vacuum infiltration or dips in solutions of $CaCl_2$ is not recommended because of their sensitive texture (Garcia et al. 1996). Finally, sensory analysis of minimally processed fruits has revealed the occurrence of bitterness and salty taste as side effects of the calcium treatment in fruits such as blackberries dipped in 2 and 4% calcium chloride (Hanson et al. 1993).

Ozone

In raspberries, a reduction of 5.6 and 4.5 log CFU/g in microbial counts of *E. coli* O157:H7 and *Salmonella enterica*, respectively, was achieved in ozone-treated fruit (50,000 ppm for 1 up to 64 min). The application of tap water solely could also reduce microbial counts of *E. coli* O157:H7 and *S. enterica* to maximums of 1.3 and 1.1 log CFU/g, compared to aqueous ozone application (Bialka et al. 2008). It is important to examine quality parameters such as fruit firmness, antioxidant capacity, color, and taste changes due to the ozone time application, as berries are considered sensitive to aqua applications. Crowe et al. (2007) found that spraying blueberries with 1 ppm ozonated water decreased the microbial counts on fruits inoculated with *Pseudomonas fluorescens* and *Enterobacter agglomerans*. Specifically, the *P. fluorescens* population decreased by 2.57 and 2.80 log units when ozone was applied for 60 and 120 s, respectively. In the case of *E. agglomerans*, ozone reduced the population>2.3 log and no further benefits were obtained in the antimicrobial effectiveness by increasing ozone exposure or by combining it with other sanitizers (i.e., hydrogen peroxide).

Sulfur Dioxide

Sulfur dioxide (SO_2) is a potent disinfectant gas used in the food industry to reduce pathogens from produce. Sulfur dioxide (SO_2), which is widely used on table grapes to prevent fungal decay during storage (Zoffoli and Latorre 2011), appears to be an important technology for reducing *B. cinerea* in blueberry fruit and minimizes gray mold prevalence during storage and transport. SO_2 treatments have also been suggested for controlling the postharvest decay of blueberries (Cantín et al. 2012). The phytotoxicity of SO_2 has limited its use; however, this compound appears to be non-phytotoxic on most blueberry cultivars (Cantín et al. 2012). Rivera et al. (2013) found the effectiveness of the SO_2 treatment against gray mold of blueberries that allows prolonged protection of the fruit during cold storage in normal atmospheres and not showing visual symptoms of phytotoxicity and only showing minor effects on fruit softening. Therefore, SO_2 fumigation is an effective and practical technology for reducing the risk of blueberry gray mold decay during storage.

Methyl Jasmonate

Pre- and postharvest treatments of fruits and vegetables with plant growth regulators and natural volatile compounds have shown positive effects on the antioxidant activity. Methyl jasmonate, a natural volatile compound, increased the contents of ascorbate, dehydroascorbate, and phenolics in raspberries during storage compared to control fruits. Moreover, methyl jasmonate-treated raspberries showed higher activities of SOD (superoxide dismutase), POX (peroxidases), APX (ascorbate peroxidase), MDHAR (monodehydroascorbate reductase), and DHAR (dehydroascorbate reductase) (Chanjirakul et al. 2006). Methyl jasmonate-treated strawberries and blueberries also showed the same results (Chanjirakul et al. 2007). This suggests that methyl jasmonate treatment enhances antioxidant activity and free radical scavenging capacity in fruits.

Irradiation

Costa-Guimaraes et al. (2013) reported that the use of irradiation on postharvest raspberry is a viable technique for the fruit export industry. The irradiation reduces weight loss and filamentous fungi and yeast count, and the dose of 2 kGy is highly effective in controlling microbial growth. Low-dose irradiation has been demonstrated to be effective for the control of decay in strawberries, used either alone or in combination with elevated CO_2 atmospheres, and is used commercially to a limited extent. Irradiation of blueberries with ultraviolet C light (up to 4000 J; 354 nm) provided a slight reduction in decay by *Colletotrichum gloeosporioides* (Perkins-Veazie et al. 2008).

Conclusion

Small berries represent a very diverse group, including a variety of red, blue, or purple small-sized and highly perishable fruits. These fruits are an important source of micro- and macronutrients, including fiber, sugars, vitamins, and minerals. Harvested fresh berries are living products and are characterized by high moisture content, active metabolism, and delicate texture, making berries very fragile and not able to store very well for long periods. In addition to that, significant postharvest losses due to mechanical injuries during transportation, physiological disorders, and microbial spoilage occur at any point from harvesting to final consumption. Thus, it is crucial to be extremely careful during harvest and postharvest handling and to sort, grade, and pack the berries in the field, avoiding excessive manipulation of the fruit. The most extended methods to maintain quality during the postharvest period are prompt precooling and storage at low temperatures. Modified and controlled atmospheres reduce microbial growth and delay senescence, but can affect bioactive compounds, with a cultivar-dependent response observed for these technologies. A set of techniques, viz., temperature management, dehydration regulation, innovative packaging and storage systems, etc. have been developed as postharvest technological tools to enhance the shelf life of berries.

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Postharvest Biology and Technology of Persimmon

Cristina Besada and Alejandra Salvador

Introduction

Persimmon fruit belongs to the botanical family Ebenaceae, in the genus *Diospyros* ('the fruit of the Gods' in ancient Greek). This genus, with more than 2000 species, originated from China, and there is evidence for its existence some centuries before Christ. It was introduced to Japan and Europe in the seventh and seventeenth centuries respectively. Most of the cultivars whose fruits are edible belong to the species *Diospyros kaki* L.f., and species *Diospyros lotus* L.f. and *Diospyros virginiana* L.f. are relevant because they are used as rootstocks.

According to the FAO statistical databases (2014), persimmon is cultivated at an area of 1,025,989 ha, with a worldwide production of 5,190,624 tons. China is the main producer, whose production has doubled in the last decade. In countries like Brazil, South Korea, and Japan, persimmon production has remained constant in the last decade, while other countries like Azerbaijan and Uzbekistan have tripled their production. In Spain, persimmon production is now five-fold higher than it was 10 years ago (MAPAMA 2017).

Persimmon fruit, which is also known as kaki, is a botanical berry. There are hundreds of persimmon cultivars of varying fruit shape from spherical to acorn, flattened or squarish, while size can be as small as 50 g and can reach as much as 300 g, depending on the cultivar. External fruit color varies from one cultivar to the next, from light yellow-orange to dark orange-red. Persimmon structure consists of a rather homogeneous parenchymatous pericarp surrounded by a thin skin covered by a waxy cuticle (Pérez-Munuera et al. 2009a). The parenchyma cells of the mesocarp are irregularly shaped, but are basically round with a diameter ranging from 100 to

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130 μm. The inside of cells is almost completely taken up by a large vacuole (Salvador et al. 2007).

Persimmons are considered a good source of readily available carbohydrates and a high content of bioactive compounds, such as tannins, polyphenols, steroids, dietary fiber, organic acids, minerals, and carotenoids, which contribute to the high antioxidant potential of these fruits (Santos-Buelga and Scalbert 2000). Recently, several studies have focused on persimmon fruit components and related them to various physiological functions. Indeed, it has been demonstrated that persimmons possess hypolipidemic and antioxidant properties, which are attributed to their water-soluble dietary fiber, carotenoids, and polyphenols (Gorinstein et al. 1998), with persimmon phenols being mainly responsible for the antioxidant effect of this fruit (Gorinstein et al. 2011). Persimmon peel has also been shown to be a valuable source of antioxidants, which under diabetic conditions, can reduce the oxidative stress induced by hyperglycemia (Yokozawa et al. 2007).

An important feature that differentiates persimmon from other fruit trees is that fruits from some cultivars are astringent at harvest, while other cultivars produce non-astringent fruits. The high soluble tannins content in fruit pulp is responsible for the astringency sensation when bitten. Astringency is the sensation that results when tannins bind salivary proteins and cause them to precipitate or aggregate, which leaves a rough 'sandpapery' or dry sensation in the mouth. Removal of astringency while preserving fruit quality has been one of the main challenges of food scientists working on persimmon. Moreover, persimmon fruit are sensitive to manifest chilling injury when stored at low temperatures. Therefore, the application of treatments to prolong the shelf life of persimmon fruit is a key step of postharvest technology.

Fruit Growth, Maturation, and Ripening

Fruit Growth

Persimmon fruits have a double sigmoidal growth curve: two periods of rapid growth (stages I and III), separated by a period of slow growth (stage II). Temperature plays an important role in both the growth and ripening of persimmon fruits (Sugiura et al. 1991), and climatic differences between persimmon-growing regions cause a wide variety in persimmon fruit growth rates (Mowat and George 1996). Candiret al. (2009) described the duration of stages I, II, and III as being 105–119, 21–35, and 21–42 days, respectively, at low and high altitudes. The cell division of persimmon fruits occurs actively at full bloom and the number of cells is significantly related to fruit size at harvest (Hamada et al. 2008). On average, increased fruit weight has been reported to be approximately2 g per day (Choi et al. 2013). At the end of stage II, fruits begin to turn yellow-orange, which indicates the occurrence of color break.

Like pruning, flower or fruit thinning are important cultural practices that affect fruit growth (Choi et al. 2014), as it improves fruit size and color. Thinning is also used to reduce biennial bearing, particularly if it is carried out in the flowering stage. Fruit set and fruit growth are sensitive to water stress (Buesa et al. 2013; Naor 2006), which may be the major cause of low fruit yields.

Maturation and Ripening

Based on their respiration and ethylene pattern, persimmon fruits are categorized as climacteric fruit. They produce a small but significant amount of ethylene during the ripening period (Itamura et al. 1991). Indeed, a low but evident peak in ethylene production is linked to the fruit maturation process (Salvador et al. 2007). Persimmons are also very sensitive to exogenous ethylene exposure and are induced to ripen with autocatalytic ethylene production by being exposed to exogenous ethylene (Wills et al. 1998; Kubo et al. 2003; Besada et al. 2010a).

Like many other fruits, change in external color is the most evident feature to take place during persimmon maturation. Thus, fruit external color changes from green to yellow-pale orange and then becomes an intense orange-red color. These changes are related to chlorophyll degradation and to carotenoids accumulation. β-Cryptoxanthin, zeaxanthin, antheraxanthin, and violaxanthin are the main carotenoids detected in persimmon skin (Ebert and Gross 1985; Niikawa et al. 2007). According to Niikawa et al. (2007), lutein mainly accumulates in the green stages, while β-cryptoxanthin and zeaxanthin abundantly accumulate in the coloring stages. The fact that skin turns to dark orange-red tones have been linked to a drastic increment in lycopene content in the most advanced maturity stages.

Changes in skin to achieve the characteristic orange-red color have often been linked to loss of firmness and to a reduction in the soluble tannins responsible for astringency (Salvador et al. 2007; Del Bubba et al. 2009; Tessmer et al. 2016). In fact, a strong and negative correlation has been observed between color and firmness values (Tessmer et al. 2016). Gradual fruit softening during ripening is related to microstructural changes in flesh, such as progressive parenchyma degradation with less swollen and more deformed cells. As maturity advances, degradation of cell walls and membranes takes place, and intercellular spaces are filled with solutes, which leads to a generalized loss of intercellular adhesion in the most advanced maturity stages. As explained later on, reduction in tannins during maturation differs between astringent and non-astringent cultivars.

The predominant sugars in persimmon are glucose, fructose, and sucrose, and a gradual increment in total sugars content generally takes place from the green stages to the mature ones (Zheng and Sugiura 1990; Senter et al. 1991; Del Bubba et al. 2009). However, in astringent cultivars, such an increase in sugars is not reflected in the measurement of total soluble solids because soluble tannins are included in the measurement of soluble solids. Therefore, the content of soluble tannins decreases, while the values of soluble solids remain constant, which indicates a parallel

increase in sugars. Del Bubba et al. (2009) reported a gradual reduction in total vitamin C from values of 0.18 g/100 g to 0.8 g/100 g during both the growth and maturation periods of two astringent cultivars. Such a drop in vitamin C does not seem to be related to a degradation process, but to increased fruit weight.

In parallel to the skin color changes exhibited by persimmon fruits during maturation, the flesh color also evolves from white to orange. Similarly to that observed in loquat cultivars, in which red-fleshed and white-fleshed fruits are distinguished, some persimmon cultivars depict a much more intense orange-colored flesh at the time of commercial harvest than others (Zhou et al. 2011). β-Cryptoxanthin has been reported as the predominant carotenoid found in the flesh of different persimmon cultivars (Del Bubba et al. 2009; Zhou et al. 2011). Lutein, violaxanthin, zeaxanthin, and β-carotene are flesh persimmon carotenoids, and their levels vary greatly among cultivars.

Differences Between Astringent and Non-astringent Cultivars

According to the level of astringency at harvest, persimmon cultivars are classified into two general categories: astringent and non-astringent (the latter is also called 'sweet' persimmons) (Yonemori et al. 2003). In both categories, the fruit astringency of some cultivars is influenced by pollination (pollination variant) and cultivars whose fruits are not affected by pollination (pollination constant). Therefore, persimmon fruits can be classified into four groups: (1) the pollination constant non-astringent (PCNA) group, which is non-astringent irrespective of seeds being present, and fruits can be eaten at harvest when they are as crisp as apples; (2) the pollination variant non-astringent (PVNA) group, which is non-astringent at harvest if fruits have seeds, and fruits are not edible when firm if they have been not pollinated; (3) the pollination constant astringent (PCA) group, which is always astringent when firm; (4) the pollination variant astringent (PVA) group, which is also astringent if pollinated, and is non-astringent only around seeds, where there are dark tannin spots.

The cultivars that belong to the PCNA group can be eaten with high firmness, since their soluble tannins content is low enough not to be sensory-detected. On the contrary, the other cultivars show a high soluble tannins content at harvest; thus, they must be subjected to postharvest deastringency treatments before being marketed. Otherwise, they must be left on trees until they overripen and can, consequently, be eaten as soft persimmons.

Fruits of both the astringent and non-astringent types are highly astringent during the immature stages. Differences in astringency between them appear during the growth and ripening stages. Non-astringent cultivars show a gradual decrease in soluble tannins, which becomes sensorially non-detectable in the first coloring stages. Thus, in non-astringent cultivars like 'Jiro' and 'Harbiye', values close to 0.03% of soluble tannins have been reported at harvest (Taira et al. 1998; Candir et al. 2009). Astringent cultivars also display a gradual reduction of soluble tannins,

but it is much less marked. Therefore, the fruits of astringent cultivars have high soluble tannins content even when fully colored and astringency becomes undetectable only in overripened stages, when fruits are completely soft. Astringent cultivars, such as 'Hiratanenashi', 'Rojo Brillante', or 'Tipo', contain a soluble tannins content that comes close to 0.5–1% (Taira et al. 1998; Salvador et al. 2007; Del Bubba et al. 2009) during the stage when fruits are completely colored and show marked firmness. Astringency is only lost in overripened stages, when soluble tannins content decrease to values of around 0.03% (Tessmer et al. 2016).

Early cessation of tannin cell development is thought to be the main cause of natural astringency loss in PCNA fruits, as it results in a diluted tannins concentration in flesh as fruits grow (Yonemori and Matsushima 1985). Yonemori and Suzuki (2009) described how tannin cells are densely distributed and interconnected as a continuous mass of tannin cells in astringent and non-astringent cultivars in cell division stages, while tannin cells distribute in a scattered manner in PCNA-type fruits and densely in PCA-type ones in late fruit development stages. Studies which have involved measuring the expression of the genes involved in flavonoid biosynthesis support this theory. According to Ikegami et al. (2005a, b), flavonoid biosynthesis genes are expressed at high levels in both PCA and PCNA types in early development stages. However, in the PCA-type cultivars, it remains high until the late development stages of fruit, which coincides with continuous tannin accumulation in fruits, while the expression of such genes in PCNA-type cultivars declines to become undetectable in late development stages, in parallel to tannins accumulation terminating.

Recently, Tessmer et al. (2016) observed the evolution of soluble tannin in two astringent and two non-astringent cultivars from the green to the overripened stages by light microscopy (LM). This technique allowed a much higher content of soluble tannins present in the flesh of astringent fruits to be viewed compared to the non-astringent ones in green stages, which must be related to the early cessation of tannins accumulation. This study also revealed that the tannins insolubilization process takes place inside tannin cells in both astringent and non-astringent cultivars. Therefore, loss of astringency in PCNA cultivars seems to be a combination of an early cessation of tannins accumulation, followed by a later process of soluble tannins that remain in flesh. However, more studies are needed in order to understand the natural insolubilization process.

Soluble tannins are well known for having a high antioxidant capacity. Therefore, the differences in soluble tannins content during the development and maturity of astringent and non-astringent fruits are also manifested in this sense. Thus, antioxidant capacity is much higher in astringent fruits than in non-astringent ones. Although, all persimmon cultivars show a declining antioxidant capacity during maturation, it is more marked in astringent than in non-astringent fruits (Tessmer et al. 2016).

Another feature that seems to be conditioned by cultivar type is the sugar accumulation. PCNA cultivars have been reported to share a common pattern, in which the glucose and fructose concentration lowers from the green stage to color break and then increases again as fruits gain their orange color, while the sucrose

concentration remains at relatively constant values (Novillo et al. 2015a).However, in non-PCNA cultivars, different sugar evolution trends are observed, depending on the cultivar: (1) glucose and fructose increase with maturation, while sucrose shows slight changes (Novillo et al. 2015a) or an increasing–decreasing parabolic-like evolution (Del Bubba et al. 2009); (2) a gradual increase in glucose, fructose, and sucrose as the maturity process advances (Senter et al. 1991; Zheng and Sugiura 1990).

Different sugar accumulation trends have been related to invertase activity (Giordani et al. 2011). Gallic and tannins acids have been reported to inhibit the activity of this enzyme (Chen et al. 2003), and, therefore, it is possible that the tannins present in persimmon also have an effect on the enzyme activity. This would explain why PCNA cultivars share a similar sugar accumulation pattern, which depends on the cultivar in astringent ones.

Factors That Affect the Maturity Process

The persimmon season is quite short, as it does not generally last more than 2or 3 months. Therefore, extending the harvest period has been one of the aims of postharvest technologists. Plant regulators have proven to be a useful tool to advance and delay fruit maturation. Preharvest applications of ethephon and paclobutrazol have been commercially applied in different cultivars to advance the maturity period. Ethephon, when metabolized by the plant, is converted into ethylene and its effect on advancing persimmon maturation has been extensively observed (Kim et al. 2004). Paclobutrazol, which is an inhibitor of gibberellin biosynthesis, is applied to soil in spring and has also been found to be effective in advancing fruit ripening (Ben-Arie et al. 1997). It is noteworthy that the application of both ethephon and paclobutrazol negatively affects the postharvest life of fruit as the postharvest softening rate is enhanced (Ben-Arie et al. 1997). Therefore, this fruit should be rapidly commercialized, given its short shelf life period.

Gibberellic acid (GA_3) has been applied to different cultivars, such as 'Triumph', 'Fuyu', and 'Hiratanenashi', to delay fruit maturation (Ben-Arie et al. 1997; Agustí et al. 2003; Lee et al. 1997; DanielI et al. 2002; Nakano et al. 1997). This growth regulator is applied by spraying the tree upon fruit color breaking. Contrarily to that mentioned for ethephon and paclobutrazol, applying GA_3 has a positive effect on preserving fruit quality during the postharvest life. It lowers the postharvest deterioration rate and allows longer fruit storage (Ben-Arie et al. 1997; Besada et al. 2008a). Ben-Arie et al. (1997) reported that the combined use of paclobutrazol and GA_3 enables precocious harvesting, followed by an extended shelf life.

The maturity process can also be affected by environmental stress situations. The application of short-term regulated deficit irrigation (50% of the recommended amount of water) has been reported to induce the fruit maturation of cultivars 'Rojo Brillante' (Intrigliolo et al. 2011) and 'Triumph' (Ben-Arie et al. 2008). Maturity

advance has been shown as increased skin color and reduced flesh firmness. Such an effect seems to depend on the fruit growth stage when water is restricted. While restricted irrigation carried out in phases II or III of 'Rojo Brillante' growth induced fruit maturation, this effect was not observed when water restriction took place in phase I of fruit growth.

Chloride stress is another environmental stress that has been recently reported to induce persimmon maturation. Besada et al. (2016) reported that fruits from trees grown under salinity conditions accumulated chloride in the calyx, which stimulated ethylene production in this tissue. In the fruits affected by slight and moderate salt stress, calyx ethylene production accelerated the maturity process, which was reflected as increased fruit color and as reduced fruit firmness. When salinity stress levels were severe, the high levels of ethylene produced by the calyx triggered autocatalytic ethylene production in other fruit tissues, which resulted in a drastic advance in fruit maturity. Besides the effect of advancing maturity, both water restrictions and salinity conditions have been reported to reduce the final fruit size.

Postharvest Handling

Harvest

Harvesting of persimmon fruit takes place in October to November. Clipping fruits from trees with cutters and leaving the calyx and a short stem attached to fruits are recommended practices. Snapping fruits from trees is an option, but only if skilled pickers have enough knowledge to avoid any kind of fruit injury.

As with many other commodities, the maturity index used to decide the harvest of persimmons is external color. Fruits need to be well developed and display the cultivar's characteristic color before being harvested. Most persimmon cultivars are considered ready for harvest when they display a full orange to orange-red color, with no visible green background. Depending on the cultivar and the seasonal conditions, the number of pickings done to complete the harvest varies from one to three.

Sugar content can be a good maturity index for non-astringent cultivars, but it is not adequate for astringent ones. This is because the measurement of soluble solids includes not only sugar, but also soluble tannins. It must be taken into account that, even for non-astringent cultivars, the content of total soluble solids required for harvest depends on the climatic conditions where cultivated. For the cultivar 'Fuyu', a soluble solid content of 15°Brix is recommended at harvest in New South Wales, while in Japan, the 'Fuyu' cultivar is harvested at 18°Brix (Agfacts 2003). Color maturity charts, which link external color with internal maturity, are useful tools to facilitate harvesting decisions.

Treatments to Remove Astringency

The postharvest application of deastringency treatments is a necessary requirement to commercialize fruits from astringent cultivars. As previously mentioned, natural astringency loss in this kind of cultivar only occurs on trees in overripened stages. Therefore, one of the traditional methods to remove astringency at harvest consists of treating fruit with ethylene (10 ppm at 20 °C) or ethephon (50–500 ppm) to enhance the maturity process. In these cases, astringency removal occurs in parallel to a drastic loss of firmness; therefore, fruits are commercialized when very soft. This implies many postharvest handling limitations, and also shortens the fruit's postharvest life. Thus, fruit submitted to astringency removal by overripening is usually commercialized in local markets.

Different methods (exposing fruits to alcohol, CO_2, N_2, or warm water) allow persimmon astringency to be removed, while preserving fruit firmness. The effectiveness of these treatments relies on exposing fruits to anaerobic conditions. Acetaldehyde accumulates in flesh under anaerobic conditions and polymerizes soluble tannins (responsible for astringency) to form insoluble compounds, which are non-astringent (Matsuo and Itoo 1982; Taira et al.1997). Accordingly, many studies have related the rate of soluble tannins insolubilization to the amount of accumulated acetaldehyde in the flesh (Taira et al. 1989; Sugiura and Tomana 1983; Pesis et al. 1988). The process of tannins insolubilization induced by increasing acetaldehyde production has been observed at the microstructural level as insoluble material appearing inside the vacuoles of some tannic cells, which were initially filled with soluble material (Salvador et al. 2007).

Among the treatments based on exposing fruits to anaerobic conditions, carbon dioxide and alcohol methods are stressed for their effectiveness and for being commercially adopted. The application of these treatments consists in enclosing fruits in specialized chambers with high CO_2 concentrations or with ethanol vapors. In both cases, the deastringency process rate is influenced by both intrinsic and extrinsic factors. With CO_2 treatment, which has been more extensively studied, temperature, CO_2 concentration, and treatment duration are the main intrinsic factors that affect its efficiency. Several studies have dealt with optimizing these parameters according to the cultivar; nowadays, the habitual conditions range from 80 to 95% CO_2 applied for 1–3 days (20 °C and 90% RH).

It is necessary to keep in mind that the process followed to remove astringency consists of two phases: an induction phase in which fruits must be maintained for a minimum period at high CO_2 concentrations and a series of reactions are triggered, and a second phase in which astringency gradually disappears and the presence of CO_2 is not essential (Gazit and Adato 1972). Matsuo and Ito (1977) determined that these two phases were temperature-dependent. The optimum temperature at which to apply treatment has been widely investigated for the astringent varieties that are mainly commercialized. However, less attention has been paid to determine the effect of temperature on astringency loss which occurs once fruits no longer remain in the presence of CO_2. Thus, more studies are needed to optimize this process phase.

Treatment duration depends not only on the applied temperature and CO_2 concentration, but also on the extrinsic treatment factors. Apart from variety (Novillo et al. 2013), treatment efficiency strongly depends on the fruit's physiological status (Taira et al. 1990). It can be generally stated that the more advanced is maturity, the more difficult it is to remove astringency and, therefore, applications need to last for more hours (Besada et al. 2010b). Apart from maturity status, it has also been reported that the previous conditions to which fruits have been exposed can also affect their response to CO_2. In this sense, the effectiveness of the astringency removal treatment with CO_2 has been shown to diminish in the fruits that have been previously stored at 15 °C for longer duration. This phenomenon has been related to structural changes at the cell level that the flesh undergoes during storage at that temperature. As storage at 15 °C is prolonged, degradation of the initial cell structure of flesh happens and intercellular spaces, which were initially empty, are progressively filled by cell material. It has been hypothesized that CO_2 diffusion through intercellular spaces becomes more difficult and leads to a low anaerobic respiration rate and, consequently, to lesser acetaldehyde accumulation. Therefore, it results in incomplete tannins insolubilization, with the subsequent residual astringency sensation (Salvador et al. 2008).

Several preharvest stresses have also been observed to affect deastringency treatment effectiveness. Thus, fruit from trees exposed to extreme water stress or to intense salinity conditions does not properly respond to deastringency treatment (Besada et al. 2016).

Of all the aforementioned factors, the treatment duration is the easiest handled in fruit and vegetable centers. With major varieties like 'Rojo Brillante' and 'Triumph', the standard duration is considered to be 24 h. Depending on factors such as temperature, CO_2 concentration, and the fruit maturity stage, this duration could be shorter or longer. Optimum treatment duration is the minimum duration needed to ensure that astringency-free fruits reach consumers.

Most research that has compared the effectiveness of ethanol and CO_2 methods revealed that CO_2 treatment is significantly more effective in removing astringency than applying ethanol (Taira et al. 1992a, b). This is linked to faster acetaldehyde accumulation in CO_2-treated fruit compared to fruit treated with ethanol (Taira et al. 1992a; Tanaka et al. 1994; Yamada et al. 2002). Slow ethanol penetration through the skin and/or slow alcohol metabolism to acetaldehyde can explain this fact (Taira et al. 1992b; Itamura et al. 1991; Tanaka et al. 1994). It has also been demonstrated that the combined use of high levels of CO_2 and ethanol treatments may increase deastringency process efficiency (Taira et al. 1992a). This can be a good alternative in those cases in which CO_2 treatment has to be prolonged to ensure complete astringency removal (e.g., when treating fruits in an advanced maturity stage at temperatures below 20 °C). It is important to note that exposing fruits to CO_2 deastringency treatment for excessively long periods may result in internal flesh browning being manifested (Fig. 1). This browning type becomes visible around the core of fruits, mainly in the area that surrounds the calyx. It has been observed that the intensity of this disorder associated with CO_2 application increases if fruits are stored at low temperature after removing astringency. In order to avoid this brown-

Fig. 1 Flesh browning associated with overexposures to CO_2 treatment (48 h) manifested in 'Rojo Brillante'. Source: Postharvest Department, Instituto Valenciano de Investigaciones Agrarias (Spain)

ing, fruits were submitted to the CO_2 treatment for the number of hours required to remove astringency. Therefore, planning the treatment application so that fruits in a CO_2 chamber are in a similar physiological stage is highly recommended because, in this way, CO_2 overexposure is avoided, as all the fruits in the chamber require similar treatment duration.

Storage

Low Temperature and Chilling Injury

Storage at low temperature is the predominant method used to preserve the postharvest life and to extend the marketing span of most perishable fruits. In temperature management during cold storage, it is important to take into account that persimmon fruits, as well as other tropical and subtropical commodities, are susceptible to chilling injury (CI) development during cold storage when held below a critical temperature.

The sensitivity of persimmon to CI is cultivar-dependent; cultivars like 'Fuyu', 'Suruga', or 'Rojo Brillante' are very chilling-sensitive, whereas others like 'Triumph' or 'Hachiya' are less susceptible to this disorder (Collins and Tisdell 1995; Arnal and Del Rio 2004).

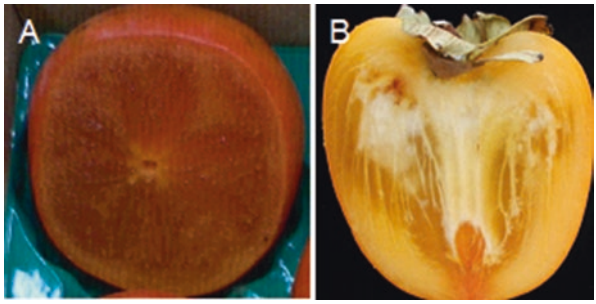

Fig. 2 Chilling injury symptoms in the cultivars 'Fuyu' (**a**) and 'Rojo Brillante' (**b**). Source: Postharvest Department, Instituto Valenciano de Investigaciones Agrarias (Spain)

CI symptoms, as well as their incidence and severity, depend on the cultivar, storage temperature, and duration. Nevertheless, firmness disorders are reported as one of the main CI manifestations in all sensitive cultivars. In the cultivar 'Fuyu', CI is initially expressed by flesh gelling (development of a gel-like consistency in flesh) and increased skin transparency through which the characteristic gel can be seen (MacRae 1987a) (Fig. 2a). In other cultivars, such as 'Suruga' or 'Rojo Brillante', the main CI symptom is a drastic loss of firmness (Collins and Tisdell 1995; Arnal and Del Rio 2004) (Fig. 2b). Other symptoms that have been associated with CI development are loss of fruit flavor, compacted flesh areas, and internal browning in 'Rojo Brillante' persimmons (MacRae 1987b; Woolf et al. 1997a; Collins and Tisdell 1995; Salvador et al. 2005). In general, CI symptoms became more severe after transferring fruits from low to ambient temperatures, although they can also be exhibited during cold storage (Woolf et al. 1997a; Zhang et al. 2010).

CI symptom development during cold storage also depends on factors such as fruit maturity and harvest time, apart from variety and storage temperature. A higher CI incidence has been reported for cultivars 'Rojo Brillante' (Salvador et al. 2005, 2006) and 'Fuyu' (Krammes et al. 2006) when fruits were picked in early maturity stages.

In different studies, CI manifestation has been related to changes in the cellular structure. Accelerated cell wall solubilization of chilling-injured fruit has been reported in persimmon cv. Fuyu (Grant et al. 1992). A microstructural study in cv. 'Rojo Brillante' showed that the drastic flesh softening, as a CI symptom, was associated with cell wall material degradation and the loss of intercellular adhesion (Pérez-Munuera et al. 2009b). Likewise, Luo and Xi (2005) reported that the primary cell wall and the middle lamella could not normally be dissolved in chilling-injured fruit when transferred to normal temperatures after cold storage. On the other hand, it has been recently reported that the low-temperature storage of persimmon leads to gradual oxidative stress, as well as major H_2O_2 accumulation, and sharp increases in catalase, peroxidase, and lipoxygenase (LOX) activities were linked to the manifestation of CI symptoms (Novillo et al. 2015b; Khademi et al. 2014).Many studies have focused on finding solutions to control CI in sensitive persimmon cultivars. Some tested postharvest strategies to alleviate CI symptoms and to allow cold storage to be prolonged in persimmon include using controlled atmospheres, heat treatments (hot water and hot air treatments), and pretreatments with 1-methylcyclopropene.

Modified Atmospheres and Controlled Atmospheres

Modified atmospheres (MA) or controlled atmospheres (CA) have become a common technology to prolong cold storage and to preserve the quality of some commodities like pears or apples (Kader 2004). In MA or CA, gases are removed or added to create an atmospheric composition around the commodity that differs from that of air. It usually involves reducing oxygen and/or increasing carbon dioxide concentrations. Using MA or CA should be considered to complement storage at proper temperatures. The benefit from using this technology depends on the commodity, cultivar, maturity stage, atmospheric composition, storage temperature, and duration (Kader 2004).

In persimmon fruits, most research has focused on using MA packages, inside which the desired atmosphere is generated passively during cold storage of fruit. Good results have been obtained with polyethylene or low-density polyethylene bags in 'Fuyu' and 'Rama Forte' cultivars (Brackmann et al. 1997). One of the main factors that limit longer storage life under MA conditions is the accumulation of ethanol and acetaldehyde, which causes off-flavors to develop and may also result in tissue browning (Ben-Arie et al. 1991).

The effect of CA on extending storage has been widely studied in some cultivars, like Fuyu. Although some atmospheres have resulted in reducing CI, they may lead to fruits that manifest external or internal browning (Burmeister et al. 1997; Brackmann et al. 2006). The incidence of skin and flesh disorders is the main limitation to storing 'Fuyu' in CA, and such disorders are reported to be due mainly to low O_2 levels and not to high CO_2 levels (Park and Lee 2008; Woolf and Ben Arie 2011). A recent study in 'Fuyu' has reported that the short-term high CO_2 treatments based on fruit exposure to high CO_2 concentrations relieve CI symptoms by preserving the integrity of cell walls and plasmalemma (Besada et al. 2015).

Studies into CA storage in other cultivars are limited. In the last few years, much interest has been shown in introducing the use of CA to some cultivars like 'Rojo Brillante'. One example is an atmosphere based on 97% N_2 + 3% air, which led 'Rojo Brillante' fruits to lose astringency and allowed fruit conservation for 30 days at 14 °C (Arnal et al. 2008). The use of an ultralow oxygen (ULO) atmosphere (1.3–1.8% O_2) removed astringency in 'Rojo Brillante' when applied at 14.5 °C, but did not control CI at 1 or 10 °C (Orihuel-Iranzo et al. 2010). Other CAs based on 4–5% O_2 + N_2offered no additional benefit for retarding CI in 'Rojo Brillante', but prolonged the storage of 'Triumph' by alleviating fruit softening and flesh gelling (Besada et al. 2014). Other authors have reported that CA (1–1.5% O_2 and 1.5–3% CO_2) storage offers the benefit of delaying softening and retarding decay development in 'Triumph'; nevertheless, fruit shelf life became inversely proportional to the storage period length (Tsviling et al. 2003).

According to the information provided above, optimum CA conditions do not seem to have been completely elucidated to prolong persimmon conservation and still depend basically on the cultivar. This is why CA conditions are rarely used commercially for persimmon fruits, and more studies are needed to optimize CA conditions in different persimmon cultivars.

Heat Pretreatments

Other treatments reported as being effective for alleviating CI in persimmon fruits are hot water or hot air applications prior to cold storage (Lay-Yee et al. 1997; Woolf et al. 1997b; Besada et al. 2008b). The response of fruit to heat treatments strongly depends on the cultivar. Before cold-storing cv. Fuyu, hot air and hot water treatments (HWTs) reduced the flesh gelling and flesh softening associated with CI (Woolf et al. 1997a, b; Burmeister et al. 1997; Lay-Yee et al. 1997). However, heat damage (mainly external and internal browning) was associated with heat treatments being applied (Woolf et al.1997b). In other cultivars, such as 'Rojo Brillante', the effectiveness of HWTs has been reported to depend on the maturity stage of fruits at harvest (Besada et al. 2008b). HWTs applied to fruits in an early maturity stage reduced CI and preserved fruit firmness and quality. However, when these treatments were applied to fruits in more advanced maturity stages, they caused irreversible epidermal breakage and external browning.

Tolerance to chilling temperatures that HWTs confer to persimmon fruits has been associated with relevant changes in cell wall degrading and antioxidant system enzymes. In cv. Rojo Brillante, HWTs have been reported to downregulate pectin methyl esterase and polygalacturonase activity, which results in greater cell wall integrity and, therefore, in fruit softening symptom alleviation. Moreover, the changes observed in peroxidase and catalase enzymes suggest that HWTs confer greater reactive oxygen scavenging capacity to fruits, and may also be implicated in alleviating CI symptoms (Khademi et al. 2014).

1-Methylcyclopropene (1-MCP)

A very positive effect of the postharvest application of 1-methylcyclopropene (1-MCP) on reducing CI symptoms has been widely reported in different persimmon cultivars. 1-MCP applied prior to cold storage has been shown to alleviate softening and gelation, which are the main symptoms in cultivars sensitive to low temperatures (Salvador et al. 2004; Kim and Lee 2005; Zhang et al. 2010). This effect of 1-MCP has been associated with preserving both the integrity of cell walls and adhesion between adjacent cells (Pérez-Munuera et al. 2009b), and reduces membrane permeability (Zhang et al. 2010) not only throughout cold storage, but also when fruits are transferred to shelf life temperatures. Reducing CI symptoms in persimmon achieved by 1-MCP treatment has also been attributed to modulate reactive oxygen species (ROS) scavenging enzymes. In 1-MCP-treated persimmons, cv. Rojo Brillante, alleviation of CI symptoms was linked to lower peroxidase activity levels and also to enhanced catalase enzyme activity, which resulted in slower H_2O_2 accumulation (Novillo et al. 2015b; Khademi et al. 2014). Similarly, Zhang et al. (2010) have reported, in cv. Fuyu, that the application of 1-MCP maintains greater antioxidant enzymes activity, such as superoxide dismutase (SOD), catalase, and also contributed to lowering the activity of oxidative enzymes, such as polyphenol oxidase (PPO) and peroxidase.

Nowadays, 1-MCP treatment is routinely applied in industry when fruits are cold-stored. Moreover, the combined use of 1-MCP and MA storage has been shown to prolong the retention of firmness and to reduce CI in 'Fuyu' persimmon (Kim and Lee 2005; Argenta et al. 2009). The combination of GA_3 preharvest treatment with postharvest 1-MCP application allowed 'Rojo Brillante' persimmon to be stored for longer than when each treatment was singly applied and, thus, delayed CI symptoms injury and extended storage time (Besada et al. 2008a).

Pathological Disorders

One of the most important postharvest diseases in persimmon is black spot disease caused by *Alternaria alternata*. This is manifested as black, firm, dry stains of varying sizes and shapes, found below the calyx or on any point of the fruit skin surface. Under field conditions, *A. alternate* develops saprophytically on dead organic matter, leaves, shoots, and plants. Under suitable rain and high humidity conditions, fruits are infected in the field via the cuticle on the epidermis or via lesions and microlesions located beneath sepals (Kobiler et al. 2011; Palou et al.2012). Black spot rot incidence is determined by latent *A. alternate* infections caused in the field before harvest, and later develop during postharvest fruit conservation (Prusky et al. 1981). Under high humidity conditions, the fungus can even develop at low temperature. That is why disease symptoms often develop during prolonged conservation periods.

This disease must be controlled by applying antifungal treatments or resistance inducers in both the field and postharvest periods. Applying GA_3 has proven to be effective in lowering its incidence (Pérez et al. 1995), and the efficacy of this treatment is associated with greater fruit firmness. The most effective postharvest treatments are modified atmospheres (30% of CO_2) and sodium troclosene or hydrochloric acid baths, either alone or combined with the fungicide prochloraz (Prusky et al. 2001, 2006; Kobiler et al. 2011).

Gray mold, caused by *Botrytis cinerea*, can also become a serious problem during persimmon postharvest life, as it grows even at low temperature, so it multiplies in fruits stored under cold conditions for long periods (Woolf et al. 2008; Palou et al. 2009). The symptoms noted during cold storage consist of very soft lesions of varying sizes, which discolor fruit skin. Lesions appear from below the calyx and spread over the peduncular region, but are also found occasionally on other fruit regions. Infected fruits that come into contact with adjacent fruits can cause rotting nests. Hot water postharvest treatments have proven to be effective for controlling the disease during long storage periods (Woolf et al. 2008).

Persimmon fruits can also display peduncular molding caused by several fungi. One of them is known as *Pestalotiopsis clavispora*, which causes dry molding that commences below the calyx and spreads all over the peduncular region. In some cases, symptoms can be seen in other fruit regions. In central regions of lesions, a white-colored cotton-like fungal mycelium develops (Palou et al. 2013b). Another peduncular mold type that has been recently detected in persimmon fruits in the Mediterranean

region is caused by *Lasiodiplodia theobromae* (Palou et al. 2013a). This pathogen produces a cotton-like white mycelium on soft, irregular light brown-colored lesions, which gradually darken when they spread from the calyx to the rest of the fruit. Symptoms are also observed, but less frequently, in the equatorial and stylar fruit regions. These diseases commence mainly in the field from latent infections, and their incidence does not tend to be high and no specific control measures are required.

Anthracnose, which is caused by *Colletotrichum gloeosporioides* and by *Colletotrichum acutatum*, may also affect persimmon fruits. Lesions are rounded and their color varies from dark brown to black (Palou et al. 2013c). They appear more frequently in equatorial fruit regions, but can also be displayed in the peduncular region. *Colletotrichum horii* also causes anthracnose symptoms in the field, and affects young shoots and fruits even before they are ripe for commercial reasons. Anthracnose caused by *C. horii* is one of the main diseases in leading persimmon production countries like Japan, China, South Korea, and New Zealand (Weir and Johnston 2010; Kwon et al. 2013).

Other fungi that can affect persimmon, but to a lesser extent, are *Penicillium expansum*, *Rhizopus stolonifer*, *Cladosporium* spp., *Trichoderma* spp., and *Mucor piriformis* (Crisosto 2004; Palou et al. 2009; Kwon and Park 2004).

Grading and Packing

Fruit grading is a common step to commercialize fruits according to their quality category. This step is carried out by passing fruits on a packing line, where they were previously cleaned by soft roller brushes. Then, fruits are graded mainly by size, but most modern packing lines also include shape, firmness, degree of blemish, and color as grading parameters. At the end of the line, fruits are generally packed by hand and the use of single-layer trays is recommended.

The persimmon surface is naturally covered by a waxy cuticle (Pérez-Munuera et al. 2009a), so it is important to keep the roller brushes in good condition to avoid natural wax from being removed. Moreover, persimmons are highly sensitive to mechanical damage and, therefore, special care must be taken to design and maintain packing line operations. The number and height of drops upon equipment transitions should be minimized, and unavoidable impacts should be prevented by cushioning with foam rubber and other materials.

The mechanical damage that fruits are exposed to during packing operations has been reported as one of the main causes of persimmon flesh decoloring (Novillo et al. 2014). Such disorders have been studied in depth in the astringent cultivar ‘Rojo Brillante’. It has been observed that two different alterations are manifested, depending on the level of astringency of fruits when mechanically impacted: ‘flesh browning’ or ‘pinkish bruising’. The former is manifested as large browned areas of the flesh that extend around the fruit; browning starts on the surface and then spread to inner regions. This disorder appears on fruits that have undergone a mechanical impact after astringency was removed by high CO_2 treatment. The latter (pinkish bruising) is seen as isolated areas of pulp (close to the skin) on which habitual

Fig. 3 Browning associated with mechanical damage in 'Giombo'. Source: Postharvest Department, Instituto Valenciano de Investigaciones Agrarias (Spain)

orange color has turned pinkish, and is detected in fruits that have suffered mechanical damage when astringent (Novillo et al. 2014).

Oxidative stress has been reported as the key mechanism that lies behind these alterations (Novillo et al. 2014). Not only mechanical damage itself but also CO_2 deastringency treatment results in ROS accumulation in the flesh of fruit. Under such oxidative conditions, tannins, which are initially uncolored, undergo an oxidation process and become colored. When the insoluble tannins of fruits that are submitted to the deastringency treatment are oxidized, they acquire a brown coloring, while the oxidation of soluble tannins present in astringent fruits allows them to acquire a pinkish color. The former are observed by the naked eye as flesh browning, while the soluble tannins are seen as 'pinkish bruising'. This pattern of response to mechanical damage is shared by most astringent cultivars. Although the intensity of these disorders depends on the cultivar, they all seem to manifest browning (Fig. 3) or pinkish bruising, depending on the level of astringency at the time of the mechanical impact. Non-astringent cultivars, however, show less sensitivity to manifesting such alterations associated with mechanical damage (Novillo et al. 2015c).

As fruit is very sensitive to manifesting such alterations, proper conditions on packing lines to avoid impacts will mean better quality fruit. From a commercial point of view, flesh browning manifestation implies greater loss of quality than pinkish bruising, as the former spreads all around fruits, while the pinkish disorder is manifested only in located areas that have suffered strong impacts. Therefore, in order to reduce fruit sensitiveness to browning, applying a deastringency treatment is recommended after carrying out packing operations.

Conclusion

The level of astringency and the degree of sensitiveness to chilling injury are the main characteristics that will condition the postharvest handling of persimmon fruit. Treatments based on high CO_2 concentrations are the most commonly applied in

order to remove astringency while preserving fruit firmness, and the conditions of the treatment must be optimized for each cultivar, having also to take into account factors such as the maturity stage at harvest and the preharvest stresses.

Nowadays, fruit storage is carried out by applying 1-MCP to reduce chilling injury. Moreover, combining 1-MCP with other technologies like controlled or modified atmospheres allows to further extend the storage period.

During postharvest handling of persimmon, it is also important to bear in mind that fruits are very sensitive to manifesting disorders associated with mechanical damages. Therefore, avoiding mechanical impacts is essential to preserving fruit quality.

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Food Safety Management of Temperate Fruits from Farm to Fork

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Introduction

Temperate fruits are usually classified by their growth habit as tree fruits (apple, pear, peach), vine fruits (grape, kiwifruit), or small fruits (strawberry, raspberry, currant, and blueberry). Around the world, temperate fruits constitute about half of the fruit consumed. Consumption of temperate fruits has increased due to their high nutritional value and health-related benefits. The temperate fruit industry has so many challenges to overcome in order to remain competitive in the long run. These are climatic factors which include irrigation, diseases, water and temperature stress, greater losses and increased costs, availability, and consumer satisfaction factors (Retamales 2011). Temperate fruits are the main players of the horticulture fruit sector and they endure postharvest losses due to mismanagement or improper techniques dealing with temperate fruits. The safety related to supply chain management in temperate fruits is very concerned with fruit waste due to improper handling, transportation, and storage conditions. The safety management in temperate fruits through the use of guidelines and standards of hazard analysis of critical control points, good agriculture practice, and standard operating procedures are used to optimize the cultivation from the field to end use. Food safety management involves the use of standards and guidelines related to the quality of produce from harvesting to the end use in an accomplished way (Kirezieva et al. 2013).

The implementation of food safety management with guidelines is different at various intervals during the production of produce. The initial production of produce

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involves good manufacturing practices, good agricultural practices, and good hygienic practices, while at the stages of consumers use and processing steps, food management involves guidelines and principles of hazard analysis of critical control points, good manufacturing practices, and good hygienic and sanitary practices. The physical, chemical, and microbial safety of produce can be ensured when food safety management consists of all steps of tackling safety, such as managemental procedures, measures, equipment, programs, tools, and controlling procedures (Little and Gillespie 2008). Assessment of safety tools in produce has been correlated with technological and managerial factors and principles for the analysis of food safety management systems (Luning and Marcelis 2006). Food quality management nowadays plays a significant role in the food industry. Changes in the system of food supply, transportation, handling, environmental situations, and consumer behavior have great impact related to food quality and safety. As a result of such changes, food quality management has an immense role in dealing with these changing requirements (Da Cruz et al. 2006). Food quality management mainly focuses on the quality of food on the basis of prescribed management rules where the food is harvested to the end use. Food quality management has the main objective of regulating and maintaining quality throughout the chain (Luning et al. 2002). Food safety management is an important element for the organization and maintenance of the production line in the food industry, which improves quality and provides maximum safety towards the risks of microbiological and chemical hazards (Ababouch 2006; Luning and Marcelis 2009).

Safety Management of Temperate Fruits During Farming

Temperate fruits in the farming and plantation stages are also prone to various types of crackdowns, which, in total, affect the end-stage growth of the temperate fruits in terms of yield, productivity, and quality. The various crackdowns are encountered in farming and plantation during irrigation, use of fertilizers and pesticides, soil quality, pest management, and agricultural practices. Growers are urged to take a proactive role in minimizing food safety hazards potentially associated with temperate fruits at the farm level. Good agriculture or horticultural practices help to reduce various types of hazards during farming.

On the farm, at the preharvest stage, the soil, fertilizer, agricultural water, pesticide solution, humans, vehicles for transportation and tillage purposes, dumped biowaste near the farm, and untreated waters are the main sources of microbial contamination (Beuchat 1996; Beuchat and Ryu 1997). Inadequate quality of water is a direct source of microbial growth, with a reduction in the quality of temperate fruits that may cause foodborne illnesses and yield reduction.

The chlorination of agricultural water with a permissible limit of 10 ppm during preharvest as a procedure for good management practice in farms and spraying farm equipment with ethyl alcohol of 70% reduces the spreading hazards (De Roever 1998). The chlorine and ethyl alcohol as sanitizers for irrigated water may

be useful in good agriculture practice programs for safety management. The use of a pest management approach during the plantation of temperate fruits controls and mitigates the pests' roles in spoilage during their cultivation. Pests such as microorganisms, rodents, and insects are major problems affecting the cultivation and quality of temperate fruits. The food safety management of temperate fruits by integrated pest management is the initial approach for the management of pests at the farm level.

Safety Management of Temperate Fruits During Harvesting

The harvesting step should be rapid in order to reduce the damage and contamination of temperate fruits with microbial pathogens, pesticides, and soil. The fresh produce must be harvested at the correct stage of maturity if it is to maintain its quality attributes throughout its postharvest life. Prematurely harvested produce is highly susceptible to shriveling and mechanical damage, and it is of inferior flavor and color when ripe and, therefore, susceptible to microbial damage (FAO 1985). Overmature produce may be fibrous, soft, and of poor eating quality in terms of sweetness, flavor, and color. It is, therefore, essential that those involved in harvesting receive training to identify the correct maturity indices for the produce concerned. 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. Temperature is the most influential factor in the postharvest life of fruits (Rudell et al. 2011). It determines the postharvest quality of fruits and has a direct effect on the growth of spoilage microorganisms. Therefore, precooling is a necessary step for fresh produce. The removal of field heat is important and is achieved by several methods, such as hydrocooling, ice topping, evaporative cooling, forced-air cooling, and vacuum cooling, that precede further processing (Kitinoja 2013). Furthermore, careful and correct harvest techniques are essential to ensuring the integrity of harvested produce and preventing rejections at the packing house.

Wounding during harvest can provide entry points for pathogens, therefore causing decay. Those involved in harvesting must be trained in the efficient and careful handling of fresh produce. Field equipment for harvesting the temperate fruits on a regular basis must be cleaned and repaired. It is important that, at the end of the picking, all equipment used for harvesting (i.e., knives, pliers) should be accounted for as being sound and unbroken to prevent physical contamination. If fruits have been harvested with unsound and broken harvesters, these fruits should be identified or, when the fruits are delivered to a packing house, the manager should be informed and the batch should be put on hold.

The regular cleaning of all harvesting equipment is essential by washing daily in a soap solution or sanitizers in accordance with the type of produce harvesting season. All harvesting equipment should be stored overnight in a closed facility, protected from rats and birds, and not contaminated with animal feces unnecessarily, which could introduce a food safety risk further down the chain. Maintaining of

harvesting equipment in sound condition is one of the food safety management steps to assure harvested fruits in good order which are free from pathogens. Proper harvesting time is necessary to maximize the quality characteristics of fruits and minimize their physiological injuries. However, few postharvest steps are promising in maintaining the quality of the individual commodity units. The relative importance of each quality parameter depends upon the commodity and the individual interest. Most of the postharvest researchers, food producers, and food handlers are product-specific, while the consumers, marketers, and economists are more likely to be consumer-oriented and rely mostly on consumer needs and demands (Shewfelt 1999). Consumers always prefer to buy fresh produce based on appearance and textural quality, as these possesses nutritional and health-promoting components. Postharvest management is an important tool aiming at maximizing quality and minimizing production losses. These include a set of postproduction practices that includes: cleaning, washing, selection, grading, disinfection, packing, and storage. These procedures eliminate undesirable elements and improve product appearance. According to the FAO (2009), postharvest practices include the management and control of temperature, relative humidity, the selection and use of packaging, and the use of fungicides. This could increase the export business of fruits and also extend the availability of fresh produce throughout the year.

Safety Management of Temperate Fruits During Cleaning

All freshly harvested temperate fruits should be free from disease agents, insects, synthetic chemicals, dirt, or dust before being packed or further processing. The postharvest diseases in fresh harvested fruits increase during prolonged storage, due to physiological changes that allow pathogens to develop in the fruit (Eckert and Ogawa 1988). Cleaning of harvested fruit from adhered microbes and pesticide residues is done with the aim of assuring food safety to enhance its storage shelf life. The cleaning process plays a significant role in a food safety management system in reducing or eliminating pathogens from fresh fruits. Cleaning and sanitizing methods for fruit surfaces is done by the application of water, chemicals, and also by mechanical treatment. It is important in terms of food safety concerns to ensure that, after sanitization, no residues left over on the surface of fruits. The water used for washing and sanitizing purposes must be clean, so that it does not become a vehicle for contamination (Parish et al. 2003). To ensure safety from pesticide residue, different methods of cleaning are adopted. The cleaning methods such as tape and ozone-treated water, ultrasonic cleaning, and boiling under different time durations have been used in strawberries and were found to be effective for the removal of 16 pesticide residues (Lozowicka et al. 2016).

Chemical methods of cleaning and sanitization of fruit surfaces usually involves washing in the presence of sanitizers, followed by rinsing with potable water. Washing and sanitizing procedures reduce the risk of chemical residues, biological pathogens, and other contaminants before or during the processing of fruits

(São José et al. 2014). Most of the cleaning and sanitizing chemicals used for the postharvest treatment of fruits include: chlorine (hypochlorites, chlorine dioxide), ozonation, hydrogen peroxide, trisodium phosphate, organic acids (acetic, lactic, citric, and tartaric acid), electrolyzed water, and calcium-based solutions (Tapia et al. 2015). However, chlorine is known to form chlorinated compounds, which are toxic. To maintain the quality, the chlorine rinses should be done under the proper regulatory standards. Also, an alternative to chlorine is chlorine dioxide, which is used up to 3 ppm as a sanitizing agent in fruits because of its high oxidizing capacity. In addition, chlorine dioxide is not involved in chlorination reactions that result in harmful by-products (Keskinen et al. 2009). Cleaning and sanitization by these chemicals should follow the standards as approved by the food regulating authorities. These chemicals must be ecofriendly to both the environment and human health (Joshi et al. 2013).

Safety Management of Temperate Fruits During Grading and Sorting

Grading and sorting based on various attributes such as weight, size, color, and sensory characteristics bring uniformity and safety, and control various processing parameters to enhance the management of safety in temperate fruits. Sorting and grading on the basis of various quality attributes reject or accept the fruits for further processing in the food industry and, hence, help in achieving the safety from microbial hazards and damaged portions of the fruit (Bee and Honeywood 2002). The sorting and grading instruments should be free from any contaminants. During grading and sorting, the damaged and unripe fruits should be removed at the quarantine stage. Good manufacturing practice should be adopted to prevent chemical contamination and cross-contamination of microbial growth in temperate fruits and to discard the damaged fruit. Personal hygiene and sanitation practices in sorting and grading minimize the potential of microbial colonies, chemical hazards, or foreign bodies contamination (De Silva 2007).

Safety Management of Temperate Fruits During Packaging and Storage

Packaging has the potential to act as an inert barrier between the food and the outside environment. It has significantly limited the chemical and microbiological ingress, thus contributing to food safety during storage. Packaging materials are developed in such a way so as to avoid the release of any hazardous components into the food. Various packing materials such as plastic, corrugated fiberboard, wood, and even sustainable materials such as bioplastics and fibers that decompose,

find their use in the packaging system. These packing materials hinder the passage of any hazardous substance inside. The fruit industry should always use safe and sterilized material for the packaging of fruit. Packaging material for fruits and their products should meet the packaging standards. If there is some fault in the packaging, the whole product is affected in terms of quality as well as safety (Jacxsens et al. 2010).

The aim of storage is to maintain fresh quality of the produce for as long as possible depending, on market conditions. Fruits should always be stored in cool and dry places. The storage life of fruits depends upon the type of fruit and the preservation technique involved. The major obstacles in achieving the fruit quality of temperate fruits are the biochemical and physiological changes within the fruit itself after harvesting and also due to the proliferation of microbial pathogens and insects in the storage environment. Fruits must be harvested at proper maturity and stored at appropriate temperatures as per the type of crop. These processes aimed to extend the postharvest life of fruit by reducing their respiration rate and the production of ethylene, minimizing metabolic activity, and retaining visual appearance. The storage area should be sanitized as per time schedules, which will help to ensure the safety of fruits till their end use.

Safety Management of Temperate Fruits During Processing

Processing is an important step of value addition that fills the gap between farm production and marketing. Consumer acceptance is assured only when there is less alteration in nutritional as well as esthetic values of the product. Before processing, fruits are to be cleaned, graded, and sorted. Fruits are processed into different products to make them available in off-seasons. Because of their high sugar content, fruits are readily attacked by yeasts and molds, which make them quality defective. The most predominant microorganisms found on fruits include *Torulopsis*, *Saccharomyces*, and *Candida*. These are mostly found on fruits because of the high sugar content present in them (Caponigro et al. 2010). Other microflora present may include *Pseudomonas* spp., *Erwinia herbicola*, *Flavobacterium*, *Xanthomonas*, *Alternaria*, *Penicillium*, *Fusarium*, and *Aspergillus* (Ahvenainen 1996). The fruits become contaminated by pathogenic microbes from humans, animals, or environmental sources upon harvest, transportation, and during processing. During processing, tissues may get damaged due to mechanical stress, resulting in the reduction of microbial safety (Badosa et al. 2008).

Food safety is of special interest for fruits when consumed raw, as they do not possess any microbiologically lethal processing (Carrasco et al. 2012). Therefore, safer methods and procedures of production and disinfection are critical while ensuring the food safety of ready-to-eat fresh fruits (Artés et al. 2009). Postharvest technologies minimize spoilage and microbial growth, including the use of chemical and physical methods, which are capable of reducing microbial contamination (Tripathi et al. 2013). Physical methods include controlled atmosphere

packaging, modified atmosphere packaging, coating, active packaging, irradiation, ultrasound, pulsed electric field, high pressure processing, and plasma treatment (Ramos et al. 2013).

To ensure adherence to food safety, Gil et al. (2015) recommended that the personnel involved in this value chain should have good knowledge on food safety, which includes: clean handling practices, personal hygiene, process hygiene, and control of cross-contamination. To protect the consumer health and maintain hygienic practices during fruit processing, industries must adopt food safety and quality assurance mechanisms. The maintenance of food quality is ensured by specific testing procedures. During processing, there should be proper monitoring procedures which could determine the efficacy of the production. If any deviation occurs, then corrective actions must be taken to avoid such problems.

Conclusion

Temperate fruits are the main players of the horticulture fruit sector and they endure postharvest losses due to mismanagement or improper techniques dealing with temperate fruits. To overcome the postharvest losses, proper safety management is a focused trend to prevent heritage sector of the temperate fruit industry. Safety management systems in temperate fruits from farm to fork are focused on the issues of quality management systems which are related to food safety to ensure human health. Food safety is addressed by having a proper understanding and control over microbiological and chemical hazards.

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Erratum to: Nutritional and Health Benefits of Temperate Fruits

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This chapter's co-author's name was incorrectly printed in the chapter. This error in name has been rectified and changed from Bvenura Callistus to Callistus Bvenura.

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