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Fruit Physiology and Postharvest Management of Strawberry

Venkata Satish Kuchi and Ch. Sai Ratna Sharavani

Abstract

Strawberry is famous for its unique flavor and delicacy among the consumers all around the world. Nowadays, the concept of postharvest management is not only confined to preserving the nutritional attributes but also extended up to flavor that includes aroma. Strawberry is a nonclimacteric fruit and its short storage life and strategic sales in the market after harvest had compelled researchers to utilize technologies like cool store, modified atmospheric packaging, controlled atmospheric storage, different packaging systems, fumigation with nitric oxide, and diversified chemical treatments to preserve fruits for longer time. To apply or innovate new technology to extend life of strawberry fruits in the postharvest area, it is necessary to understand the physiology and biochemistry of fruits. This chapter reviews fruit physiology, recent trends, and future prospects in the postharvest management of strawberry.

Keywords: strawberry, postharvest, flavor, quality, packaging, storage, chemical treatment

1. Introduction

Strawberry (*Fragaria × ananassa*) belongs to family Rosaceae. It is cultivated throughout the world. Fruits have high vitamin C content which are consumed fresh. They are also processed into pastry or pie filling mostly. They provide great health benefits. Regular consumption of anthocyanins (found in berries) reduces the risk of heart attack. The antioxidants (like kaempferol, quercetin and anthocyanins) which are present in fruits reduce the formation of harmful blood clots which are associated with strokes. The antioxidants neutralize free radicals present in human body, inhibit tumor growth, and decrease inflammation in the body. Strawberry consumption decreases the risk of heart stroke due to high potassium content. For the above reason, strawberries were suggested to the people with blood pressure. It also counteracts the effects of sodium in the human body. According to the National Health and Nutrition Examination Survey, less than two of American adults meet the daily 4700 mg recommendation for potassium (K⁺). Strawberries are a smart fruit choice for diabetics as they have a lower glycemic index (40) than many other fruits.

Strawberries are low-growing herbaceous plants. Roots are fibrous in nature; basal leaves arise from crown, which are compound. Flowers are generally white, rarely reddish, are borne in small clusters on slender stalks arising from the axils of the leaves which look like the surface-creeping stems. As a plant ages, the root system becomes woody, vegetative propagation occurs from the “mother” crown which sends out runners (e.g., stolons) that touch ground and root. Botanically, the

fruit of strawberry is “accessory fruit” and is not a true berry. The flesh consists of the greatly enlarged flower receptacle in which many true fruits, or achenes, are embedded, which are popularly called seeds.

Strawberries are commercially cultivated both for immediate consumption and for processing as frozen, canned, or preserved berries or as juice. Due to the perishable nature of the berries and the improbability of mechanical picking, the fruit is generally grown near centers of consumption or processing and where sufficient labor is available. The berries are handpicked directly into small baskets and crated for marketing or put into trays for processing. Early crops can be produced under controlled conditions (glass or plastic covering). Strawberries are very perishable and require cool dry storage.

To innovate a new technology for extending storage life of strawberry fruits in the postharvest area, it is necessary to understand the physiology and biochemistry of fruits. This chapter reviews fruit physiology, recent trends and future prospects in postharvest management of strawberry.

2. Physiology and biochemistry of strawberry during ripening

Fruit ripening involves dramatic changes in the color, texture, flavor, and aroma of fleshy fruits. Both the palatability and nutritional quality of fruit are highly dependent on its consumption at an optimum stage of ripeness. However, ripe fleshy fruits are also perishable commodities, and this presents problems for fruit production, harvesting, storage, and marketing.

The general ripening programmes (**Figure 1**) displayed by strawberry typically include: (i) modification of color through the alteration of chlorophyll, carotenoid, and/or anthocyanin accumulation; (ii) modification of texture via alteration of cell turgor and cell wall structure; (iii) accumulation and modification of acids, sugars and volatiles that affect nutritional quality, aroma and flavor; and (iv) increased susceptibility to pathogens and herbivores [2]. These changes in flavor, color, aroma and texture make fruit ripening a complex process, which must be very tightly regulated. Fruit species are categorized as either climacteric or nonclimacteric, based on physiological differences in their ripening patterns [3].

Strawberry is a nonclimacteric fruit and fast growing, with a short postharvest life. During development, receptacle growth was due to a combination of cell division and cell expansion until seventh day after petal fall, and thereafter, only

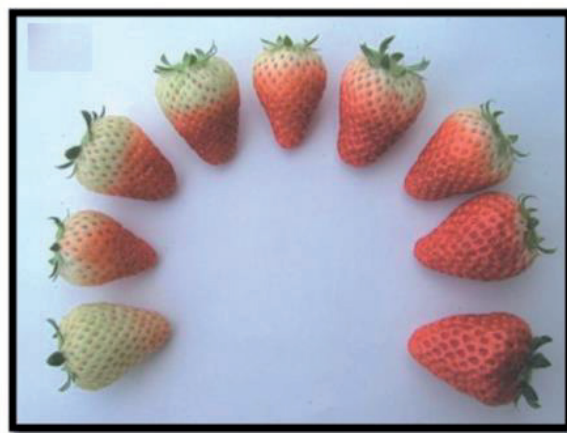


Figure 1. Stages of fruit development [1], from left to right color development from tip toward receptacle (anthocyanin development).

cell enlargement occurs [4]. Accumulation of sugars, water and synthesis of cell walls were observed until 21–28 days after petal fall [5]. In strawberry and other fruits like grapes, growth may continue after initiation of ripening process [6]. Fruit enlargement continues until it reaches 25 per cent red or more, when chlorophylls have been completely degraded and anthocyanins begin to build up.

2.1 Role of hormones in fruit ripening

Auxin, the first plant hormone identified, may act as an inhibitor of ripening in some nonclimacteric fruits [7, 8]. In strawberry, it appears that auxin from the externally located achenes (seeds) inhibits the ripening of the fleshy receptacle [9]. Fruit development continues till the auxin level falls below the critical level in the receptacle and achenes, thus permitting ripening [10]. Therefore, removing the achenes promotes ripening, while treating strawberries with synthetic auxins delays ripening [11, 12].

2.2 Softening of fruit during ripening

During ripening, the primary cell wall of fleshy fruits shows structural and compositional change [11], which leads to loss of firmness and facilitates the attack of pathogens, enhancing postharvest decay and reducing the quality of fresh fruit. During ripening, water soluble polyuronides increases (**Figure 2**), whereas, there will be decrease in insoluble, covalently bound pectins. Concurrently, depolymerization of pectins occurs, which has been linked with the action of a number of hydrolases, mostly polygalacturonases (PG) [14]. Xyloglucan, the main component of hemicelluloses in dicotyledons, is also considered to play a vital role in cell wall structure, since it forms cross-linkages among the cellulose polymers. Xyloglucan endotransglycosidases, endoglucanases, and expansins contribute to the depolymerization of xyloglucans at the time of ripening [14].

Three major components of fruit organoleptic quality are flavor, sweetness, and acidity. Fruit with intense flavor also have high titratable acidity and high soluble solids [15]. Fruit soluble solids, sugars, titratable acidity, and organic acids at

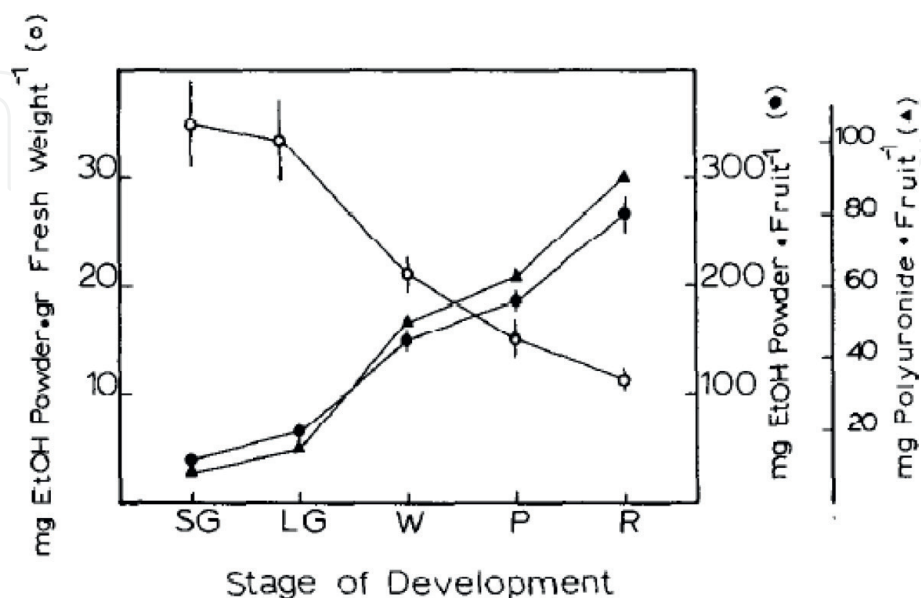


Figure 2. Changes in polyuronides during fruit ripening [13], changes in ethanol insoluble powder, and total polyuronides during strawberry development (○) mg ethanol insoluble powder per gram fruit fresh weight (●) mg powder per individual fruit (▲) mg total polyuronic per individual fruit.

maturity are quantitatively inherited [16, 17]. Numerous biochemical changes are observed during strawberry development and especially during fruit ripening [18]. The major soluble constituents of maturing and ripe strawberries are soluble sugars and organic acids [6, 19].

2.3 Sugars

The major soluble sugars in strawberries are glucose [1.4–3.1% fresh weight (FW)], fructose (1.7–3.5% FW), and sucrose (0.2–2.5% FW) [6]. Glucose and fructose concentrations increase continuously during fruit development, while sucrose accumulates mostly during maturation [19].

2.4 Organic acids

The major organic acid is citrate, and its concentration ranges from 4 to 12 mg·g⁻¹ FW. This acid contributes greatly to fruit titratable acidity, which declines gradually during fruit development. The sugar/organic acid ratio is a major parameter of strawberry taste [6].

2.5 Amino acids

Of the other soluble constituents of strawberries, amino acids may also directly affect fruit taste, as was shown by the sensory evaluation of another fleshy fruit, peach [*Prunus persica* (L.) Batsch] [20]. Moreover, some amino acids are flavor precursors [20]. The major amino acids in strawberries are asparagine, glutamine, and alanine [21]. Anthocyanins (0.5–1.5 mg/g fruit weight) are a major component of the fruit, while ascorbic acid (0.3–1.2 mg/g fruit weight) makes an important contribution to the fruit nutritional value. Among the insoluble constituents, starch is present in young fruit and disappears before ripening [5].

3. Harvesting

Harvesting is generally practiced after 3–4 months from planting. Strawberries are the sweetest when they are fully ripened on the plant. It is better to leave them on the plant for a day or two till they turn red. To ensure ripeness, taste test can be made. During harvesting berries, care should be taken as ripe ones bruise very easily. For harvesting, snap the stem just above the berry to remove them from the plant. Store harvested berries out of direct sunlight in some cool place, such as a refrigerator immediately after picking to increase the storage time. Strawberries can be consumed fresh or preserved by freezing or dehydrating and canning.

3.1 Robotic harvesting

The pericarp of a strawberry is so soft that workers must harvest the fruits carefully to avoid damage. The fruits are harvested early in the morning, before the temperature of the fruits rises and they become soft; workers need to select mature red fruits from among the many fruits that have set. These factors result in long working hours during the harvest period. Mechanical harvesting trials have been conducted on the assumption of once-over picking, but utilization of this strategy is not yet widespread [13]. The commonly used selective harvesting method requires high-tech and sophisticated robot technology. In short, it is essential to design an

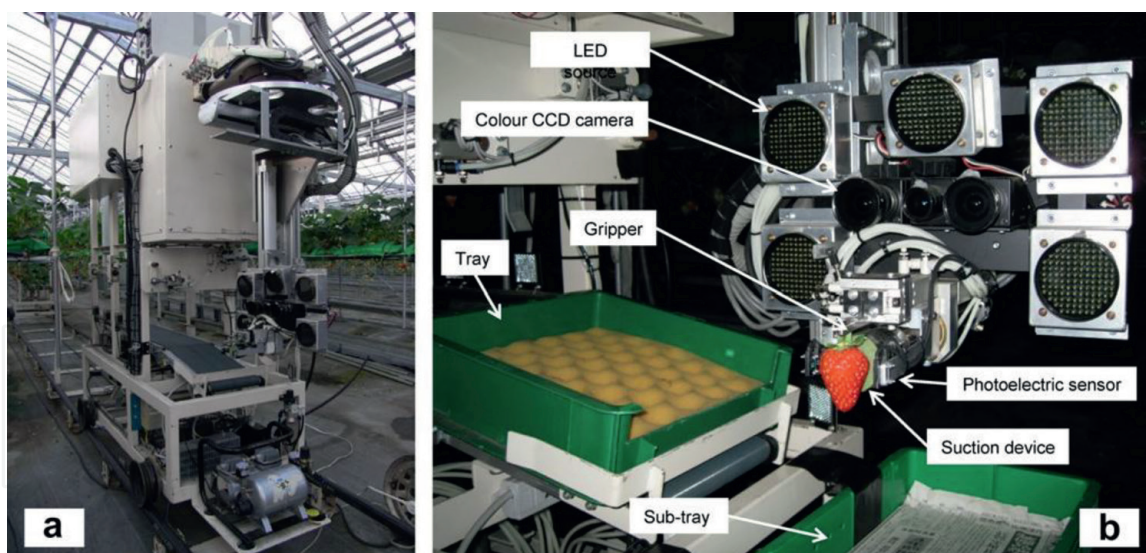


Figure 3.
 Robotic harvesting in strawberry [1]: (a) high tech sophisticated harvester from a distance and (b) enlarged view with different parts of robotic harvester.

smart robot with human-like perceptive capabilities; for example, the machine would need to analyze fruit position, assess maturity level and pick the fruit without injuring the pericarp. Basic studies on robotic harvesting were initiated with orchard fruits [22]; since then, such studies have been ongoing in a number of countries [23]. This skill has then been used for vegetable fruits. Tillett [24] reviewed various robot prototypes and clarified the importance of the manipulator design and its application to practical use. Several studies have applied robotic technology to fields in greenhouses for instance, cucumber harvesting [25], strawberry harvesting (**Figure 3**) [1] tomato harvesting [26], aubergine harvesting [27] and de-leafing [28]. However, the performance and cost have not met commercial requirements.

4. Precooling

Rapid removal of field heat from freshly harvested commodities is called precooling. It slows down ripening, respiration, senescence, decay, and water loss, thus helping for quality maintenance and prolonging shelf life [29]. Rapid precooling is most essential for produce such as strawberry which has a high rate of metabolism. The process of removal of field heat can be achieved by different methods that includes room cooling (RC), forced-air cooling (FA), hydrocooling (HC) contact icing, and vacuum cooling, each differing in efficiency of heat removal. Strawberries are typically cooled used forced air cooling. Delay in cooling of harvested strawberries results in reduction of number of marketable berries due to increased water loss, softening, and losses of sugars and vitamin C [30]. Thus it is usually recommended that strawberries should be cooled to temperatures near 0°C as soon as possible (within 1 h) after harvest to limit deterioration and decay [31, 32]. However, for commercial strawberry operations, this idea is rarely achieved due to factors such as the volume of strawberries handled, cooling and handling equipment availability, and capability, economics, energy, and market conditions. Hydro-cooling is a more rapid precooling method, but strawberries are not hydro-cooled commercially, due to decay problems by the water left on the berries after Hydro-cooling [29, 32]. Park et al. [33] proved that effectiveness for keeping the freshness of strawberries was best achieved by precooling at 4°C and storage at 4°C, respectively.

5. Postharvest treatments

5.1 Physical treatments

Physical methods include high or low temperature treatments, irradiation and use of modified or controlled atmospheres.

5.1.1 High-temperature treatments

High temperature treatments can control insect pests, prevent pathogen infection, induce resistance to chilling injury, slow fruit ripening, and extend postharvest shelf life [34, 35]. Application of thermal treatments reduced the fungal development, ripening rate and extended the shelf life in strawberry [36]. Strawberry shelf life may be improved by an appropriate thermal treatment that could be used instead of fumigation to allow a more advantageous usage of this fruit in the commercial chain.

5.1.2 Low temperature

Freezing of fruits and vegetable is one of the most common ways for maintaining the quality of these products. Frozen storage of strawberry, at 18°C after 7 months, had a specific effect on color but no significant different in total anthocyanin was observed [37]. Decrease of anthocyanin content in frozen storage strawberry, at 20°C after 6 months, depending on variety was 11–27.5% [38]. The storage temperatures of 18 and 24°C were best for preserving the qualitative characteristics (color, texture, flavor and wholeness) of the strawberries [39].

5.1.3 Irradiation

Alternative control methods that do not leave residues, such as postharvest UV-C radiation, have been shown to prevent decay and improve fruit quality [40–44]. Ultraviolet C (UV-C) radiation is known for preventing fungal decay and enhancing phytochemical content in fruit when applied postharvest. Additionally, it has been reported that postharvest UV-C radiation induces secondary metabolites production that protect fruit against abiotic and biotic stresses [45]. Furthermore, these metabolites (phenolic compounds, anthocyanins, carotenoids) also play an important role in fruit quality with impact on human health [46]. UV-treated fruits had a lower respiration rate, higher titratable acidity and anthocyanin content, and were firmer than the untreated fruits. The percentage of free sugars increased faster in UV treated fruits at the beginning of the storage period [40]. Freshly harvested strawberries of cv. Kent, at 25–50% red were exposed to UV-C at doses of 0.25 and 1.0 kJ/m² and stored at 4 or 13°C after exposure which has resulted in controlling the decay caused by *Botrytis cinerea* at both storage temperatures and extended the shelf-life of the fruits by 4–5 days [40].

5.2 Chemical treatments

5.2.1 Fumigation

Methyl bromide fumigation is the current treatment for postharvest strawberry disinfestation of pests such as western flower thrips [*Frankliniella occidentalis* (Pergande)] and two-spotted spider mite (*Tetranychus urticae* Koch). Due to the reduced availability and increased cost of methyl bromide (as a result of its phase out in 2005 for all uses except quarantine treatments), an alternative treatment is

desirable. Low molecular weight volatile compounds such as ethyl formate (EF) are produced by several fruits and vegetables which are important components for flavor and aroma and also have been revealed to have insecticidal and fungicidal properties [47]. Before the product reaches the market, these low molecular weight volatile compounds can potentially undergo degradation to biogenic levels in the tissues of treated commodities which is an advantage over conventional chemicals, which can persist as residues in food products.

Ethyl formate is currently in the process of being formulated with CO₂ for commercial use in Australia and New Zealand. Simpson et al. [48] showed that CO₂ in combination with Ethyl formate significantly reduced pest population (Western flower thrips and Red spider mite) without causing any damage to the fruit quality.

Nitrous oxide (NO) has been found to be ubiquitous in postharvest climacteric and nonclimacteric fruit, vegetables and flowers, with higher levels present in unripe than in ripe tissues [49, 50]. Since ethylene accumulation initiates ripening of climacteric produce and enhances senescence of nonclimacteric produce, it was speculated that application of NO might retard ripening and senescence in post-harvest tissues [51]. Strawberries are a high value fruit but marketing is limited by a short postharvest life. The postharvest life can, however, be extended by minimizing the concentration of ethylene in the atmosphere around fruit [51, 52].

Wills et al. [53] performed fumigation in strawberry in an atmosphere of anaerobic nitrogen for up to 2 h at 20°C with nitric oxide concentrations ranging from 1.0 to 4000 ml l⁻¹ then held at 20 and 5°C in air containing 0.1 ml l⁻¹ ethylene which had resulted in extension of postharvest life.

Hydrogen sulfide acts as an important gaseous regulator in plants like nitrous oxide. Fumigation with hydrogen sulfide (H₂S) gas released from the H₂S donor NaHS increased the postharvest shelf life of strawberry fruits depending on dose used [54]. Strawberry fruits fumigated with various doses of H₂S has resulted in significantly lower rot index, maximum fruit firmness, and minimum respiration intensity and polygalacturonase activities than controls. Treatment with H₂S maintained higher activity levels of enzymes catalase, ascorbate peroxidase, guaiacol peroxidase, and glutathione reductase and lowers the activities of lipoxygenase relative to untreated (controls). It also reduced hydrogen peroxide, malondialdehyde, and superoxide anion to levels below control fruits during storage. Furthermore, H₂S treatment maintained higher contents of soluble proteins, reducing sugars, free amino acid, and endogenous H₂S in fruits. This interprets that H₂S plays an antioxidative role in enhancing postharvest shelf life of strawberry fruits [54].

5.2.2 *Salicylic acid*

Salicylic acid (SA) is a simple phenolic compound. It is recognized as a plant growth regulator, because of its external application effect on many plant growth physiological processes [55]. Salicylic acid (2 mM) effectively increased strawberry ascorbic acid content, fruit total antioxidant potential, total soluble solids and prevented fungal contaminations [56]. They also studied the reversible effect of SA and recommended plant SA treatment in all different growth stages like vegetative, fruit development and postharvest stage. Fruits of the plants of strawberry cv. Camarosa which received SA (0.03 mM) after 7 days at 28°C in their nutrient solution had less weight loss and decay, higher firmness and hue angle than control [57].

5.2.3 *Calcium dips*

Among secondary nutrients, calcium acts a major role in maintaining the quality of fruit and vegetables. Increasing the “Ca” content in the cell wall of fruit tissue

can aid to delay softening and mold growth and decrease the occurrence of physiological disorders [58]. Common techniques like dipping and vacuum or pressure infiltrations are used to increase cell wall Ca content of fruit tissue after harvest. The firming effect can be explained by the crosslinks formation between the carboxyl groups of polyuronide chains found in the middle lamella of the cell wall; Ca also increases cell turgor pressure [59, 60] and stabilizes the cell membrane [61]. Calcium dips have been employed to improve firmness and extend the postharvest shelf-life of a wide range of fruit and vegetables. In strawberries, CaCl_2 dips in combination with heat treatment or modified atmosphere storage and refrigeration increase calcium content and fruit firmness and delay postharvest decay [62, 63]. Calcium dips were effective in decreasing surface damage and delaying both fungal decay and loss of firmness in strawberries, compared to untreated fruit [64].

5.2.4 Coatings

Highly perishable fruits such as berries and tropical fruits are appropriate products to protect with coatings because they are expensive and exhibit a short storage life (**Figure 4**). Coatings can act as moisture and gas semi-permeable barriers, resulting in control of microbial growth, preservation of color and texture [64]. Strawberries, as a typical soft fruit, have a high physiological postharvest activity. As a consequence, they have short ripening and senescence periods that make marketing of this high-quality fruit a challenge.

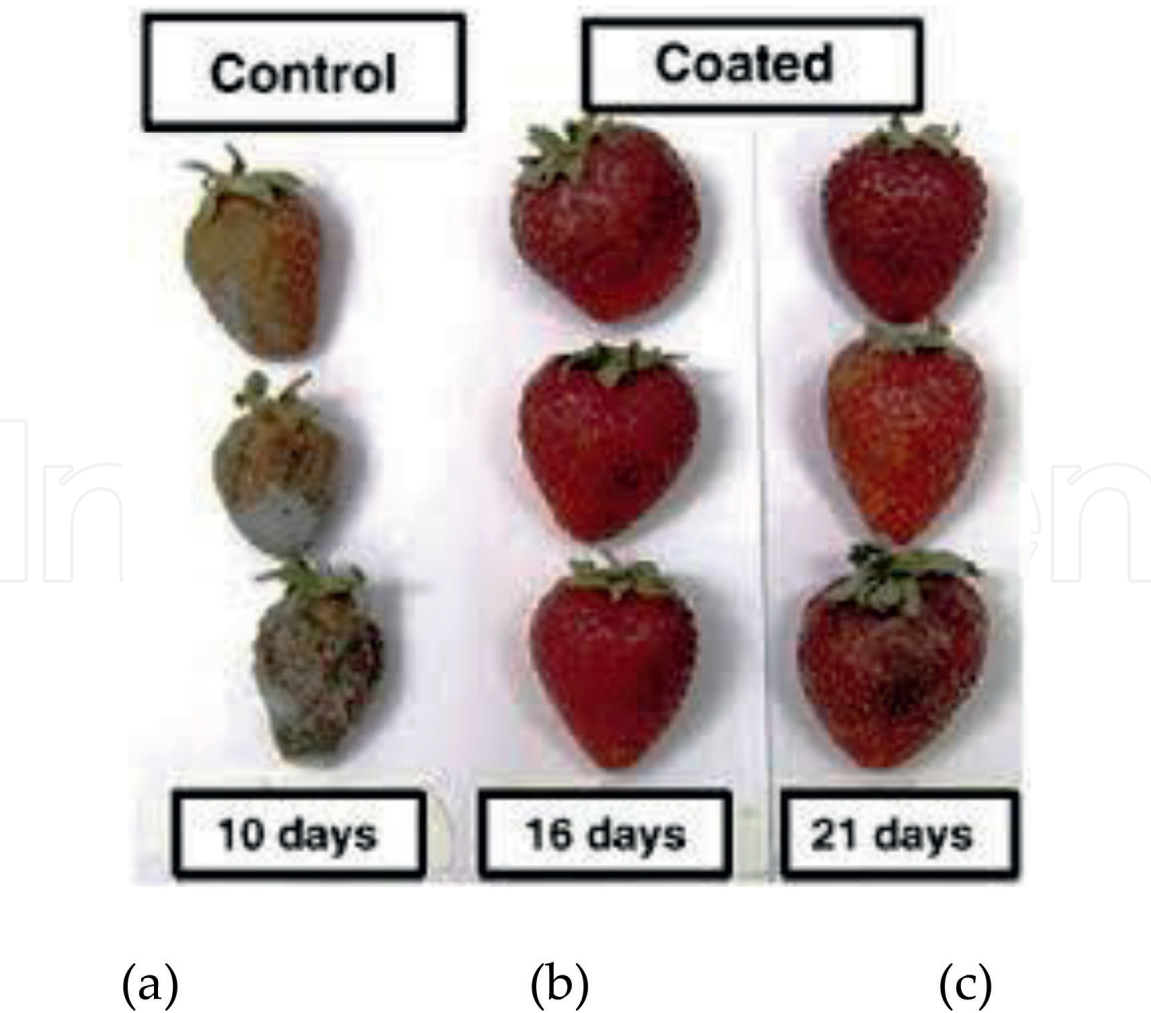


Figure 4. Fruits treated with coatings have prolonged shelf life: (a) untreated fruits have 10 days of shelf life with improper color development; and (b) shelf life of fruits treated with coatings on 16th day and (c) with coatings on 21st day.

5.2.4.1 Chitosan

Chitosan, a high molecular weight cationic polysaccharide, theoretically should be an ideal preservative coating material for strawberries. It has been shown to inhibit growth of several fungi [65], to induce chitinase, a defense enzyme. Due to its ability to form semi-permeable film [66], chitosan coating can be expected to modify the internal atmosphere as well as decrease the transpiration losses. Therefore a delay in ripening and control of decay by means of chitosan coating could result. Romanazzi et al. [67] found that the commercial chitosan formulation was as effective in the control of gray mold and Rhizopus rot of strawberries immersed in these solutions and kept for 4 days at $20 \pm 1^\circ\text{C}$.

Chitosan-based edible coatings used to extend the shelf-life and enhance the nutritional value of strawberries at either 2°C or 88% relative humidity (RH) for 3 weeks or -23°C up to 6 months which resulted in reduced drip loss and helped to maintain textural quality of frozen strawberries after thawing. In addition, chitosan-based coatings containing calcium or Vitamin E significantly increased the content of these nutrients in both fresh and frozen fruits [68]. There was significant reduction in severity of decay and shelf-life extension on immersing strawberries stored at either 5 or 10°C in chitosan solutions of 0.5, 1.0 and 1.5 g/100 mL for 5 min at 20°C as compared to untreated [69]. Chitosan sprays (2, 4 and 6 g/l) significantly reduced post-harvest fungal rot and maintained the keeping quality of the fruit [70].

5.2.4.2 Starch based coatings

Edible coatings can be made from food materials such as cellulose derivatives, proteins, starch, and other polysaccharides (regarded as GRAS). Starch is the most usually used agricultural raw material for biodegradable films [71]. The film-forming capacity of starches was due to presence of Amylose. Plasticizer, another important component of edible films is required to overcome film brittleness and improve extensibility and flexibility of the films. They reduce intermolecular forces and increase the movements of polymer chains. Plasticizer must be compatible with the film-forming polymer; hydrophilic compounds such as polyols (glycerol, sorbitol, polyethylene glycols) and lactic acid are frequently used in hydrophilic film formulations [72]. The effect of plasticizer on water vapor and gas permeabilities is controversial, depending on matrix, plasticizer type, and environmental conditions [73–75].

Starch-based coatings can be applied to extend storage life of strawberries (*Fragaria ananassa*) stored at 0°C and 84.8% relative humidity. Coatings made with starches with the higher amylose content decreased WVP and weight losses and retained fruit firmness for longer periods [76]. The coating of strawberries with cassava starch + chitosan provided the best results, with less than 6% of loss in fruit mass, lower counts of yeast and psychrophilic microorganisms and the best appearance according to the sensory analysis [77].

5.2.4.3 Botanical coatings

Aloe vera (AV), a novel edible coating was used for fruit storage [78, 79] which has antifungal activity against several pathogenic fungi including *Botrytis cinerea* [80]. AV coatings modify the internal gas atmosphere, reduce moisture loss, softening, respiration rates, delay oxidative browning and reduce microorganism proliferation in fruits [79, 81–83]. *Aloe vera* + Ascorbic acid treatments in strawberries delayed weight loss; reduced total aerobic mesophilic, yeasts, and molds populations; and had higher SSC, vitamin C concentrations, and titratable acidity [84].

Cactus mucilage is one of the edible coating which is used for increasing shelf life of strawberries [85]. Mucilages are generally hetero-polysaccharides obtained from plant stems [86]. They may find applications in cosmetics, food, pharmaceutical and other industries. The complex polysaccharide is a part of dietary fiber and has the capacity to absorb more amounts of water by dissolving and dispersing itself and forming gelatinous or viscous colloids [87]. Cactus mucilage as a coating is its low cost.

5.3 Storage

5.3.1 Modified-atmosphere packaging (MAP)

Modified-atmosphere packaging (MAP) of fruit and vegetables is becoming a popular method of extending shelf life [88]. Strawberries fumigated with acetic acid at 5.4 mg/L followed by modified atmosphere packing were found to be free of decay compared to 89% rotted for the control fruit stored for 14 days at 5°C [89].

5.3.2 Controlled atmosphere storage

The use of a carbon dioxide enriched atmosphere is an extensively used postharvest practice to manage and control fungal decay in freshly harvested fruits and vegetable products. Numerous studies have revealed that controlled atmosphere storage of different cultivated strawberry varieties may enhance their shelf life by slowing down both fungal decay and senescence. These effects are linked with the reduction of respiration and ethylene production rates [51, 90, 91]. Exposure of fruits to high levels of CO₂ during cold storage showed enhancement of firmness [92, 93] and resistant to decay [51]. However, combinations of high CO₂ and low O₂ atmospheres improve most strawberry quality traits, increase in generation of off-flavor compounds like ethanol and ethyl acetate, producing an adverse sensory effect [94]. The atmosphere of high CO₂ and high O₂ do not ease these off-flavor problems and show to persuade a synergistic effect that even increases the assembly of fermentative metabolites [94, 95]. Allan and Hadwiger [96] studied that 10% CO₂/11% O₂ combination had efficiently prolonged 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.

5.4 Packaging and transport

In order to avoid deterioration during storage, strawberries need to be well packed immediately after harvest. Cold-chain system is regularly used to conserve the quality and flavor for a prolonged period.

5.4.1 Cold-chain system

Precooled strawberries are stored at a low temperature in a cold store, or transported for marketing in a refrigerated van. This system enables the fruits to remain fresh until they reach the consumers. In a well-organized cold-chain system, cold air should be well dispersed within the boxes used for packaging. Furthermore, boxes should not lose their shape even if they become moist. Each box should hold the correct amount of fruit, and be of an appropriate size to reduce the cost of distribution.

5.4.2 Packaging films

Packaging of fruits with polymeric films is often used to prevent moisture loss, to protect against mechanical damage, and to achieve a better appearance [97].

Packaging strawberries with plastic films immediately after harvest is only technique to prevent water loss during storage. The water loss may lead to shriveling and a dull appearance of the epidermis having a negative effect on the appearance of the fruit.

Different types of packaging films include:

Perforated cellophane sheets (CS): these were placed on top of the baskets and fixed with elastic bands.

Low density polyethylene bags (PB): these were heat-sealed after introducing one or more baskets per bag.

Polyvinyl chloride films (PVC): PVC films has resulted in better fruit weight and firmness retention of fruits of strawberry especially in the last 7 days of storage [98].

The use of Low density polyethylene bags as packing films in strawberry has resulted in the lowest weight losses, conductivity and degree of fruit decay, together with the highest firmness values [99].

5.4.3 Hydrophilic starch films

They offer good barrier to oxygen and carbon dioxide transmission but a poor barrier to water vapor under certain conditions of relative humidity (RH) and temperature [97, 100]. These characteristics are favorable for preservation of quality of fruits and vegetables, since they lead to a decline in respiration rate by restricting the exposure to ambient O₂ and increasing internal CO₂, thus delaying ripening. The poor water vapor barrier allows mobility of water across the film, thus preventing water condensation that can be a possible source of microbial decay in soft fruits and vegetables [101].

5.4.4 Corrugated fiber board boxes

This improved method of packaging consists of an outer box made of corrugated fibreboard (**Figure 5**), having a capacity of 6 kg, and 6 inner boxes made of cardboard, each box have a holding capability of 1 kg fruit. The external box is 54 cm long × 36 cm wide × 9 cm high, and was designed to occupy 96% of the base area.

5.4.5 Ventilation holes

In order to facilitate the movement of cold air, ventilation holes (**Figure 6(a)** and **(b)**) were made on the sides of the box and the internal partitions. Ventilation



Figure 5.
Packaging of strawberries: (a) plastic punnets (b) Corrugated fiber board box.



Figure 6.
 (a) Strawberries packed in corrugated fiber board boxes (side view) and (b) strawberries packed in corrugated fiber board boxes with laminated polyethylene (top view).

holes to surface area ratio in the outer box are 4.5 per cent, whereas, that of the internal partitions is 10.5 per cent. The passage of cold air through the holes shortens the precooling time and makes more uniform cooling.

In addition, the ventilation holes are circular and measures less than 20 mm in diameter, which are small enough to avoid the strawberries from being caught in the holes. The box is a folding type to prevent shape distortion, which repeatedly happens to other packaging boxes as a result of dampness. With this novel box, the strawberries can be securely stored for a longer time.

6. Conclusion

Strawberry, which possesses attractive color, palpable taste and significant mineral and vitamin content, is highly perishable. In the present trend where consumers want food to be of medicinal value, strawberry is the promising one. By following appropriate postharvest practices growers can minimize losses and preserve the fruit in fresh form with good quality for longer duration. Further, there are tremendous prospects of commercial utilization of strawberry for extraction of natural color and have great potential as raw material for production of diverse value added processed product and thereby develop agro-industry. Strawberry can be regarded as the fruit crop of future.

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