16 Fruits and Vegetables – Processing Technologies and Applications

Nutsuda Sumonsiri and Sheryl A. Barringer
Department of Food Science and Technology, The Ohio State University, Columbus, Ohio, USA

16.1 Raw materials

16.1.1 Chemical composition

The chemical composition of fruits and vegetables depends on many factors including variety, weather, cultivation, degree of maturity at harvesting, and storage conditions. Table 16.1 shows the composition of some raw fruits and vegetables. The most important component in fruits and vegetables is water, which ranges from 70% to 95% and 10% to 20% of the weight in wet crops and dry crops, respectively (Haard, 1984). Due to the high quantity of water in fruits and vegetables, a decrease in the moisture content causes significant wilting and weight loss, and causes both undesirable and desirable changes during processing (Brecht et al., 2007).

The majority of the solids in most fruits and vegetables is carbohydrates, including starches, sugars, cellulose, hemicelluloses, and pectins (Haard, 1984; FAO, 1995). In most fruits and vegetables, carbohydrates represent approximately 75% of the dry weight. Starches are normally found in intercellular plastids or starch granules to provide energy and reserve energy in plants, seeds, and tubers. In some crops, such as potato, sweet potato, and cereals, the starch concentration can be up to 74% of the dry weight (Brecht et al., 2007; FAO, 1995; Hucl & Chibbar, 1996). The sugars found in edible plants include fructose, glucose, and sucrose. Some fruits and vegetables have a sugar content of more than 20%, such as ripe banana, while other fruits and vegetables do not contain significant amounts of sugar, such as avocado, which contains a sugar content of approximately 4% of the dry weight (Richings et al., 2000). Some sugar alcohols, including but not limited to sorbitol, mannitol, and xylitol, are also found in fruit tissues (Brecht et al., 2007). Cellulose, hemicelluloses, pectin, and lignin are cell wall constituents that produce supporting structures in plant tissues. They do not provide any energy because they cannot be digested by humans in the upper digestive tract. However, they are considered a good source of beneficial dietary fiber, and are broken down in the colon to provide prebiotic benefits.

After harvesting, fruits and vegetables still undergo active biological processes, such as respiration, ripening in fruits, and senescence. In some fruits and vegetables, these activities cause significant changes in the quality so the postharvest storage conditions and processing steps need to be carefully conducted to prevent these changes. For example, the level of sugar in potatoes increases up to 5–10 times the original sugar concentration at harvest if they are stored below 10°C after harvesting. The high sugar content in these potatoes can cause Maillard browning reactions during further processing steps, especially drying and frying. In ripe sweet corn, the opposite reaction is of concern. During storage, the level of sugars decreases and starch is produced, causing losses in flavor and texture (Cottrell et al., 1993).

In most fruits and vegetables, lipids are found in cytoplasmic membranes and in the endosperm (Brecht et al., 2007; Haard, 1984). The amount of lipid typically varies from 0.1% to 1% of the fresh weight; however, some fruits and vegetables have high amounts of storage lipids, such as avocado (up to 15.5%), oilseeds (up to 18.5%), and nuts (up to 65.2%) (Haard, 1984; USDA Agricultural Research Food Processing: Principles and Applications, Second Edition. Edited by Stephanie Clark, Stephanie Jung, and Buddhi Lamsal. © 2014 John Wiley & Sons, Ltd. Published 2014 by John Wiley & Sons, Ltd. 363
The lipids found in fruits and vegetables are phospholipids, glycolipids, and triacylglycerols. Other lipid-like substances, such as carotenoids, are also found in many crops, for example, orange, pineapple, cantaloupe, carrot, and tomato. Waxes are found on the surfaces of leaves, fruits, and seeds (Brecht et al., 2007), and can decrease moisture loss during storage and processing. Waxes on fruits and vegetables also slow down the rate of sodium hydroxide diffusion during lye peeling (Floros & Chinnan, 1989).

In most fruit, proteins and other nitrogenous compounds can be found at less than 2% of the fresh weight (Haard, 1984) while vegetables contain 1.0–5.5% of these compounds (FAO, 1995). Some crops, such as vegetables in the family Leguminosae, accumulate storage proteins and contain up to 40% protein (Haard, 1984). The legume seeds, including peas, beans, lentils, peanuts, and soybean, are good sources of all the essential amino acids, except methionine and cysteine (Brecht et al., 2007). The presence of amino compounds and reducing sugars causes Maillard browning reactions, resulting in changes in color and flavor during processing, especially in dehydration and concentration processes.

Fruits and vegetables are a significant source of vitamins. The vitamin content depends on variety and conditions during growth, postharvest storage, and processing. Edible plants contribute approximately 50% of vitamin A, 58% of thiamin, 26% of riboflavin, 47% of niacin, and 94% of vitamin C intake in the US diet (Brecht et al., 2007). In general, plants do not have vitamin A, but they contain β-carotene, which is converted into vitamin A after consumption. Orange and yellow crops, and green leafy vegetables, such as squash, sweet potatoes, carrots, and spinach, are an excellent source of β-carotene. Vitamin C can be found in many fruits and vegetables, for example, strawberry, oranges, guava, and kale. Most vitamins, especially C, A, and B, are sensitive to changes in pH, air, light, and heat; therefore, there is usually at least 30% loss of these vitamins during processing (Karmas & Harris, 1988).

Minerals in fruits and vegetables are in the form of salts of organic or inorganic acids or complex organic combinations. There are more mineral substances found in vegetables than in fruits. The mineral content in edible plants varies from less than 0.1% to 5% of the fresh weight. The minerals found in edible plants are calcium, iron, potassium, magnesium, sulfur, phosphorus, and nitrogen (Brecht et al., 2007). Fruits and vegetables that are rich in minerals include cabbage, tomatoes, carrots, raspberries, cherries, peaches, and strawberries (FAO, 1995). Minerals are more stable than vitamins during processing; however, they can be increased or decreased due to different processing steps and conditions. For example, calcium, potassium, and sodium levels are frequently increased during processing of canned vegetables from hard water uptake or addition of minerals during processing (Rickman et al., 2007).

Organic acids, such as citric acid, malic acid, and tartaric acid, are present in many fruits, such as oranges, lemon, apples, and grapes, and provide tartness and decrease the tendency for microbial spoilage. During storage and ripening, the organic acids of many fruits, such as apples, pears, and oranges, decrease; therefore, degree of acidity and sugar content are used to predict ripeness for harvesting. Organic acids are present at up to 50 mEq acid per 100 g of tissue in acidic crops (Spanos & Wrolstad, 1992).

Some acids, such as chlorogenic acid, affect browning of fruits and fruit juices, particularly the enzymatic browning reaction, which is catalyzed by the presence of oxygen and PPO (polyphenol oxidase), resulting in

<table>
<thead>
<tr>
<th>Fruit/vegetable</th>
<th>Water (g)</th>
<th>Carbohydrate (g)</th>
<th>Protein (g)</th>
<th>Fat (g)</th>
<th>Vitamin C (mg)</th>
<th>Thiamin (mg)</th>
<th>Potassium (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>85.56</td>
<td>13.81</td>
<td>0.26</td>
<td>0.17</td>
<td>4.6</td>
<td>0.017</td>
<td>107</td>
</tr>
<tr>
<td>Tomato (ripe)</td>
<td>94.52</td>
<td>3.89</td>
<td>0.88</td>
<td>0.20</td>
<td>13.7</td>
<td>0.037</td>
<td>237</td>
</tr>
<tr>
<td>Potato</td>
<td>83.29</td>
<td>12.44</td>
<td>2.57</td>
<td>0.10</td>
<td>11.4</td>
<td>0.021</td>
<td>413</td>
</tr>
<tr>
<td>Green beans</td>
<td>90.32</td>
<td>6.97</td>
<td>1.83</td>
<td>0.22</td>
<td>12.2</td>
<td>0.082</td>
<td>211</td>
</tr>
<tr>
<td>Apricot</td>
<td>86.35</td>
<td>11.12</td>
<td>1.40</td>
<td>0.39</td>
<td>10.0</td>
<td>0.030</td>
<td>259</td>
</tr>
<tr>
<td>Strawberries</td>
<td>90.95</td>
<td>7.68</td>
<td>0.67</td>
<td>0.30</td>
<td>58.8</td>
<td>0.024</td>
<td>153</td>
</tr>
<tr>
<td>Carrot</td>
<td>88.29</td>
<td>9.58</td>
<td>0.93</td>
<td>0.24</td>
<td>5.9</td>
<td>0.066</td>
<td>320</td>
</tr>
<tr>
<td>Avocado</td>
<td>73.23</td>
<td>8.53</td>
<td>2.00</td>
<td>14.66</td>
<td>10.0</td>
<td>0.067</td>
<td>485</td>
</tr>
</tbody>
</table>

the formation of brown quinones. Many phenolic acids in plants, such as coumaric, caffeic, and benzoic acids in apple, pear, and grape, also have a large effect on flavor and color of fruit and vegetable products, especially fruit juices and wines (Spanos & Wrolstad, 1992). Moreover, benzoic acid can serve as an antifungal agent in some fruits, such as cranberry (Brecht et al., 2007).

16.1.2 Pigments

16.1.2.1 Chlorophyll

16.1.2.1.1 Location and function in the plant

Chlorophylls, magnesium complexes derived from porphin, are green, oil-soluble pigments found in the chloroplasts of green plants, photosynthetic bacteria, and algae. In most green plants, chlorophyll \( a \) and \( b \) are in the ratio of 3:1. Chlorophyll \( c \) and \( d \) are commonly found in marine algae and red algae, respectively (von Elbe & Schwartz, 1996). In the plant, chlorophyll plays an important role in producing carbohydrates from \( \text{CO}_2 \), water, and light using photosynthesis.

16.1.2.1.2 Effect on color changes

The color of chlorophyll is affected by heat, \( \text{pH} \), and light. During heating, chlorophyll is converted to the olive green or brown color of pheophytin, pyropheophytin, pheophorbide, and pyropheophorbide since two hydrogen ions easily replace the magnesium atom in chlorophyll (Figure 16.1) (von Elbe & Schwartz, 1996). The heat stability of chlorophyll is affected by \( \text{pH} \). Chlorophyll is only heat stable at \( \text{pH} \) above 9.0 (von Elbe & Schwartz, 1996). At neutral conditions, the color of chlorophyll is rapidly changed by thermal treatment. Acid conditions (\( \text{pH} \) below 5.8) change the color of chlorophyll to olive green, even under cold conditions (Maharaj & Sankat, 1996).

In healthy plant tissues, light cannot destroy chlorophyll since it is protected by carotenoids and other lipids that have weak linkages with chlorophyll (von Elbe & Schwartz, 1996). However, the presence of light increases the degradation of chlorophyll in plant leaves during senescence or when cells are damaged during processing (Kar & Choudhuri, 1987; von Elbe & Schwartz, 1996).

16.1.2.1.3 Reaction with additives

Since chlorophylls are stable in basic conditions, sodium carbonate or other alkali could theoretically protect the bright green color in some vegetables. However, alkali is not commercially used because the texture of the vegetable is softened, unpleasant flavors are developed, and some vitamins, such as vitamin C and thiamine, are destroyed under alkaline conditions and heat treatment (FAO, 1995). A patented process using \( \text{Zn}^{2+} \) or \( \text{Cu}^{2+} \) salts can retain the bright green color of vegetables. These ions substitute for the \( \text{Mg}^{2+} \) atom in chlorophyll and form zinc or copper complexes of chlorophyll derivatives, which are bright green and stable to heat. The chlorophyll derivatives are allowed for use in canned foods, candy, soups, and dairy products in most European countries. In the US, \( \text{Zn}^{2+} \) is allowed only in vegetables and \( \text{Cu}^{2+} \) is allowed in confections (LaBorde & von Elbe, 1996).

16.1.2.2 Anthocyanins

16.1.2.2.1 Location and function in the plant

Anthocyanins are water-soluble pigments in a subgroup of flavonoids that provide a wide range of colors in fruits and vegetables, including purple, violet, magenta, blue, and red. The pigments can be found in berries, grapes, eggplant, and cherries. Anthocyanins have a wide structural diversity with as many as 250 different structures in plants, depending on the cultivar and maturity. The structure of anthocyanin is based on 2-phenylbenzopyrylium of flavylium salt. The factors affecting the different structures of anthocyanins are the number, types, and sites of sugars attached to the molecules, number and types of aliphatic or aromatic groups attached to the sugars, and number of hydroxyl and/or methoxy groups. When the attached sugar in an anthocyanin is hydrolyzed, the non-sugar form of anthocyanin is called an anthocyanidin. There are six common anthocyanidins found in food: pelargonidin, cyanidin, delphinidin, peonidin, petunidin, and malvidin (von Elbe & Schwartz, 1996).

16.1.2.2.2 Effect on color changes

The color of anthocyanins is sensitive to \( \text{pH} \), enzymes, and metal ions during extraction from tissues of fruits and vegetables, as well as during processing and storage of the product. There are four possible forms of anthocyanins in an aqueous medium or foods with different \( \text{pH} \), including the blue quinonoidal base, the red flavylium cation, the colorless carinobil pseudobase, and the colorless chalcone (Figure 16.2). These structures play an important role in color changes of anthocyanins at various \( \text{pH} \). For example, the color of some anthocyanins turns from red to blue with the increase of \( \text{pH} \) in the
0–6 pH range since the red flavylium dominates at low pH and the blue quinonoid dominates as pH is increased (von Elbe & Schwartz, 1996).

There are two groups of enzymes that can affect the color of anthocyanins: glycosidases and polyphenol oxidases. Glycosidases can hydrolyze glycosidic linkages and produce sugars and the agylcone, resulting in decreased solubility and color loss of anthocyanins. Polyphenol oxidases can oxidize diphenols in the presence of oxygen and produce brown $o$-benzoquinone, which is usually undesirable, especially in fruit juice processing (Yokotsuka & Singleton, 1997).

16.1.2.2.3 Reaction with additives

Anthocyanins are decolorized in sulfur dioxide solution, which can be either reversible or irreversible, depending on the concentration of sulfur dioxide. Some fruits containing anthocyanins are held in sulfur dioxide solution at low concentration (500–2000 ppm) to reduce microbial spoilage during storage. This process causes color loss of the fruits; however, a desulfuring process through washing can restore the color before processing. During the production of maraschino and candied cherries, a high concentration of sulfur dioxide (0.8–1.5%) is used to bleach the color.

![Diagram of the degradation of chlorophyll a.](image-url)
of anthocyanins and this effect is irreversible (von Elbe & Schwartz, 1996; Wrolstad, 2009). However, at very low concentration (30 ppm), sulfur dioxide can be used to prevent enzymatic browning in sour cherry juice (Unten et al., 1997). In frozen strawberry, sucrose is also added to stabilize the color of anthocyanins and reduce the browning reaction by functioning as a diluent and interrupting the condensation reactions, as well as serving as an inhibitor of polyphenol oxidase (Wrolstad et al., 1990).

Metal complexes of anthocyanin are commonly found in plants, especially in flowers (Takeda, 2006; von Elbe & Schwartz, 1996). The anthocyanins can react with metal ions, such as Al, Sn, and Fe, and turn violet or blue; therefore, the inside of a metal can has to be lacquered to protect the color of fruits and vegetables containing anthocyanins.

16.1.2.3 Carotenoids

16.1.2.3.1 Location and function in the plant

Carotenoids are fat-soluble pigments that have a wide range of colors, from yellow through orange to red, such as the orange carotene in carrot, peach, apricot, and citrus fruits, the red lycopene in tomato and watermelon, and the yellow xanthophylls in corn and squash. The general structural backbone of carotenoids is a symmetrical molecule of isoprene units, which are covalently linked in a head-to-tail or a tail-to-tail fashion. The most common carotenoid in the plant is β-carotene (Figure 16.3) (von Elbe & Schwartz, 1996).

The carotenoids are often found along with chlorophylls in the chloroplasts and play an important role in
photosynthesis and photoprotection in plants. In the human diet, some carotenoids, such as β-carotene, α-carotene, γ-carotene, and cryptoxanthin, can be converted into vitamin A. β-Carotene has the greatest provitamin A activity since it has two β-ionone rings, which is a retinoid structure (see Figure 16.3). Fruits and vegetables containing provitamin A carotenoids can provide 30–100% of the vitamin A required for the human diet (von Elbe & Schwartz, 1996).

16.1.2.3.2 Effect on color changes
Carotenoids are stable to pH, heat, and water leaching. They can be degraded by oxidation due to the presence of light, oxygen, or lipoxygenase, resulting in loss of both color and vitamin A activity. In the degradation of carotenoids due to enzyme activity, carotenoids react with peroxides, which are produced when lipoxygenase catalyzes oxidation of unsaturated fatty acids. Since carotenoids can be easily oxidized due to several conjugated double bonds in their structure (see Figure 16.3), they are considered antioxidants, which can quench singlet oxygen and prevent damage to the cell from oxidation.

16.1.2.3.3 Reaction with additives
L-ascorbate is usually used to prevent the oxidation of carotenoids and preserve the color in beverages and margarine (Delgado-Vargas et al., 2000). Green tea polyphenols can also be added to beverages and margarine to prevent discoloration of carotenoids since the phenolic hydroxyl group stabilizes the peroxide radical and prevents the oxidation of β-carotene (Unten et al., 1997).

16.1.2.4 Betalains
16.1.2.4.1 Location and function in the plant
Betalains are water-soluble pigments found in vacuoles of plant cells that produce similar colors to carotenoids and anthocyanins. The color range of betalains varies from the red of betacyanins to the yellow of betaxanthins. These pigments can be found in only 10 families of the order Centrospermae, including red beets, cacti, Swiss chard, and amaranth. The basic structure of betalains (Figure 16.4) is formed by the condensation of amine with betalamic acid (von Elbe & Schwartz, 1996). Betalains are believed to play an important role in preventing damage from UV radiation in plants that can tolerate extremely dry environments with high salinity, such as the ice plant (Ibdah et al., 2002), and protecting the plant tissue from pathogens in vegetables that grow underground, such as the red beet (Stafford, 1994).

16.1.2.4.2 Effect on color changes
The color of betalains is unstable to changes in pH. Under alkaline conditions, betacyanins dominate and produce a bluish red or bluish violet color. Under acidic condition, the color of betalains is yellow due to the formation of 14,15-dehydrobetanin (Mabry et al., 1967).

16.1.2.4.3 Reaction with additives
The presence of metal cations, such as Cu²⁺, Al³⁺, Fe²⁺, and Fe³⁺, increases the degradation rate of betalains due to the formation of metal-pigment complexes (Herbach et al., 2006). Ethylenediamine tetra-acetic acid (EDTA) can form complexes with metal ions and therefore increase the stability of betalains (Pasch & von Elbe, 1979).

16.1.3 Enzymes
16.1.3.1 Enzymes affecting color
There are two enzymes that have a significant effect on the color of fruits and vegetables: lipoxygenase (EC 1.13.11) and polyphenol oxidase (EC 1.10.3.1). Lipoxygenase can be found in plants, animal tissues, and mushrooms (Oliw, 2002). It initially catalyzes the oxidation of unsaturated fatty acids and produces hydroperoxides and free radicals, which are responsible for bleaching chlorophylls and carotenoids in unblanched stored vegetables, resulting in loss of color.
Polyphenol oxidase is an enzyme catalyzing the oxidation of phenolic compounds, which include anthocyanins as well as several of the flavor compounds, found in plants, animals, and some microorganisms (Ruenroengklin et al., 2009). The products from the reaction, usually $o$-benzoquinone, are not stable, and are further oxidized and polymerized, and finally produce the brown color of melanins. This is responsible for the undesirable brown color in cut fruits and vegetables, such as peaches, potatoes, apples, lettuce, and bananas, and especially in tropical fruit juices. However, some brown and black colors from these reactions, found in coffee, raisins, and prunes, are desirable (Whitaker, 1996).

16.1.3.2 Enzymes affecting texture

The texture of fruits and vegetables is significantly affected by two enzymes, which work together: pectin methylesterase (EC 3.1.1.11) and polygalacturonase (EC 3.2.1.15). Pectin methylesterase converts pectin polymers into pectic acid, which polygalacturonase can hydrolyze. These enzymes, therefore, cause a significant decrease in texture, or softening of fruits and vegetables, especially those rich in pectin, such as tomatoes, apples, bananas, and avocado. In the processing of many tomato products, including ketchup, pizza, and spaghetti sauces, a high viscosity is desired; therefore, the hot break process, which is a rapid high heat treatment at above 82°C for 15 sec, is applied after grinding to inactivate the enzymes. During the production of tomato juice, a low viscosity is desired so the cold break process uses a temperature less than 66°C to speed up the activity of these enzymes and decrease viscosity of the product (Madhavi & Salunkhe, 1998).

16.1.3.3 Enzymes affecting flavor

Enzymes in fruits and vegetables that can cause great changes in flavor are peroxidase (EC 1.11.1.7) and lipoxygenase during the oxidation of unsaturated fatty acids and other compounds. These enzymes can cause the formation of aromas, such as $cis$-3-hexenal, $cis$-3-hexenol, $trans$-2-hexenal, and 2-methylbutanal, in lettuce, corn, broccoli, green beans, cauliflower, and peas (Azarnia et al., 2011; Deza-Durand & Petersen, 2011). Therefore, vegetables need to be blanched prior to freezing or drying to stabilize their flavor. Peroxidase is very resistant to heat. The thermal inactivation of this enzyme is in the temperature range of 70–95°C, so it is usually used as an indicator of proper thermal treatment of the product (Morales-Blancas et al., 2002).

16.1.3.4 Effect of temperature, pH, and water activity on enzyme activity

Temperature, pH, and water activity affect enzyme activity, which causes changes in the product quality. Temperature has a significant effect on the stability of enzymes and velocity of the reaction. As temperature increases, the enzyme activity increases. However, as temperature increases beyond 60–70°C, enzymes become unstable and there is reduced activity due to the denaturation of the enzyme (Whitaker, 1996).

pH also has a great effect on enzyme activity. Each enzyme has a particular optimal pH depending on its type, source, and other conditions, such as temperature, substrate concentration and accessibility, enzyme concentration, and the presence of inhibitors. For example, the optimal pH for lipoxygenase in soybean is 7–9, while that for polygalacturonase in tomatoes is 4 (Whitaker, 1996).

Water activity has a significant effect on enzyme activity since most enzymes are in aqueous media. Some water is required for enzyme activity to mobilize and solubilize the reactants. As the moisture content increases, enzyme activity increases since there is enough water to dissolve the substrate and increase the diffusion at the active site. Enzyme activity decreases at low water activity; for example, phospholipase has no activity on lecithin at water activity below 0.35 (Whitaker, 1996).

16.2 Basic processing

Basic processing of fruits and vegetables usually starts with grading, washing, cooling, and peeling, depending on the characteristics of the crops and the final products. Figure 16.5 shows the production figures for the commercial fruits and vegetables discussed in this chapter.

16.2.1 Grading

One of the initial steps fruits and vegetables go through is grading, to determine the price paid to the farmer. This is done at the processing facility or at a centralized station before going to the processing facility. Individual companies may set their own grading standards, use the voluntary USDA grading standards, or use locally determined standards, such as those of the Processing Tomato Advisory Board in California. The farmer is paid based on the percentage of fruits and vegetables in each category. Typically, companies hire USDA graders or hold an annual grading school to train their graders.
16.2.1.1 Tomato grading

The USDA divides tomatoes for processing into categories, the highest being A, followed by B, C, and culls (USDA, 1983a). Grading is done on the basis of color and percentage of defects. Color can be determined visually by estimation of what percentage of the surface is red, with an electronic colorimeter on a composite raw juice sample, or with a portable colorimeter on a whole tomato. Defects include worms, worm damage, freeze damage, stems, mechanical damage, anthracnose and other disease, mold, and decay. The allowable percentage of extraneous matter may also be specified. Extraneous matter includes stems, vines, dirt, stones, and trash.

Tomatoes for canning whole, sliced or diced are graded on the basis of color, firmness, defects, and size. Solids content is unimportant, unlike in tomatoes for juice or paste. Graders must be trained to evaluate and score color and firmness. Color should be a uniform red across the entire surface of the tomato. Color is graded using USDA-issued plastic color comparators, the Munsell colorimeter or the Agtron colorimeter, or the tomato is ground into juice and used in a colorimeter with a correlation equation to convert it to the Munsell scale. Firmness, or character, is important to be sure the tomato will go through canning and remain intact. Soft, watery tomatoes or tomatoes possessing large seed cavities give an unattractive appearance and therefore receive a lower grade. Size is not a grading characteristic per se, but all tomatoes must be above a minimum agreed upon size.

The Processing Tomato Advisory Board inspects all tomatoes for processing in California. Their standards are similar to those of the USDA, but more geared for the paste industry. They inspect fruit for color, soluble solids, and damage. A load of tomatoes may be rejected for any of the following reasons: >2% of fruit is affected by worm or insect damage, >8% is affected by mold, >4% is green, or >3% contains material other than tomatoes, such as extraneous material, dirt, and detached stems (California Department of Food and Agriculture, 2001).

16.2.1.2 Potato grading

Potatoes for French fry processing are divided into two categories during grading: US no. 1 processing and US no. 2 processing, based on the size of the potatoes (USDA, 1983b). The potatoes in US no. 1 processing must be more than 5 cm in diameter or 4 oz in weight. The whole potatoes in US no. 2 processing must be more than 3.8 cm in diameter or the usable pieces, which are the portion of potato after trimming, must be more than 4 oz in weight. Potatoes in both categories have to be free from serious damage, freezing injury, blackheart, late blight,
tuber rot, insects, worms, southern bacterial wilt, bacterial ring rot, soft rot and wet breakdown, loose sprouts, dirt, and foreign material. The number of potatoes in different size categories may also be specified.

Besides the size of potatoes and defects, which are the basic requirements, specific gravity and fry color are optional tests during grading of potatoes for French fries. For specific gravity, potatoes are randomly taken from the lot and at least three corrected readings are averaged. The specific gravity is determined by the weights of the potatoes in air (5000 g) and in water at a specific temperature using the USDA-approved equipment. The reading from each test is corrected for temperature variations using correction factors provided by the USDA. In the test for fry color, 20 potatoes are randomly chosen and then sliced into 3.23 cm² strips and fried in oil for at least 3 min at 176.67°C or 2.5 min at 190.56°C. The fry color can be determined by using the Munsell Color Standards for Frozen French Fried Potatoes.

Potatoes for chipping are also divided into two categories during grading: US no. 1 and 2, based on the size of potatoes (USDA, 1978). The US no. 1 potatoes for chipping should be more than 4.8 cm in diameter while US no. 2 potatoes for chipping should be more than 4.4 cm in diameter. Potatoes in both categories have to be free from serious damage, freezing, blackheart, late blight tuber rot, nuts of nut sedge, southern bacterial wilt, bacterial ring rot, and tuber moth injury, soft rot, and wet breakdown. Similar to potatoes for French fry processing, specific gravity and fry color are optional tests for potatoes for chipping. The test for specific gravity is the same but the fry color is determined by frying at least 40 potato slices (1.3 mm thick) in oil for at least 1 min and 40 sec at 185°C. The color of fried potato chips should be more than a reading of 25 on a photoelectric colorimeter approved by the USDA, such as Agtron M-30A or M-300A.

16.2.2 Washing

Washing is a critical control step in producing fruit and vegetable products with a low microbial count. After harvesting, fruits and vegetables are washed to eliminate soil, dirt, surface microorganisms, mold, insects, Drosophila eggs, fungicide, insecticide, and other pesticide residues (FAO, 1995). The efficiency of the washing process will determine microbial counts in the final product. Spoiled fruits and vegetables should be removed before washing to minimize the contamination of washing tools, equipment, and produce during washing. The washing process should reduce the surface microorganisms by a six-fold, or 1-log, reduction and there should not be any molds and yeast in the water from the final wash. Lye or surfactants may be added to the water to improve the efficiency of dirt removal; however, surfactants have been shown to promote infiltration of some bacteria into fruits and vegetables by reducing the surface tension at the pores (Bartz, 1999), which jeopardizes food safety. The washing step also serves to cool fruits and vegetables. Since some of them are harvested on hot summer days, washing removes the field heat, slowing respiration and therefore quality loss.

Several methods can be used to increase the efficiency of the washing step. Agitation increases the efficiency of soil removal. The warmer the water spray or dip, up to 90°C, the lower the microbial count (Adsule et al., 1982), although warm water is not typically used because of economic concerns. Immersion or spraying is usually used with the application of detergents, 1.5% HCl solution, warm water (approximately 50°C), or high water pressure (for spray or shower washing). For washing vegetables, detergents or sanitizers can be used in equipment designed for the shape, size, and fragility of the vegetables, such as a flotation cleaner for peas and small vegetables, and a rotary washer with overhead spray for fragile vegetables.

Chlorine is frequently added to the wash water at 100–150 ppm. Chlorine will not significantly reduce microbial counts on fruits and vegetables itself because the residence time is too short. However, it is effective at keeping down the number of microorganisms present in the flume water (Heil et al., 1984). When there is a large amount of organic material in the water, such as occurs in dirty water, chlorine is used up rapidly, so it must be continuously monitored. Other potential alternative sanitizers, such as peroxyacetic acid and chlorine dioxide, are also suggested for some fruits and vegetables such as lettuce leaves and apples (Wisniewsky et al., 2000).

16.2.2.1 Tomato washing

Tomatoes are typically transported in a water flume to minimize damage to the fruit. Therefore, tomato washing can be a separate step in a water tank or it can be built into the flume system (Figure 16.6). The final rinse step uses pressurized spray nozzles at the end of the soaking process. Flume water may be used in a counterflow system, so that the final rinse is with fresh water, while the initial wash is done with used water. In either system, the first flume frequently inoculates rather than washes the
tomatoes because all the dirt in the truck is washed into the flume water (Heil et al., 1984). When the water is reused, high microbial counts on the fruit may result if careful controls are not kept.

16.2.2.2 Potato washing

A washing step is necessary before processing potatoes in order to remove stones, soil, debris, and pesticide residues (Schorneck, 1961; Zohair, 2001). Potatoes are usually dumped into a vat with an adjustable conveyor system that contains washing water. A water tank is also used to separate stones from the tubers, since the stones settle to the bottom. The tank also removes debris floating on top (Figure 16.7).

Several solutions are reported to be efficient for eliminating the pesticide residues in potatoes during washing, including citric acid, acetic acid, hydrogen peroxide, sodium chloride, and sodium carbonate, at a concentration between 5% and 10% in wash water (Soliman, 2001; Zohair, 2001). The acidic solutions are more efficient than neutral and alkaline solutions in removing pesticides, especially organochloride compounds.

16.2.3 Cooling

Cooling is used to remove the field heat from fresh fruits and vegetables before further processing. This reduces water loss, slows down respiration and ripening (for fruits), and minimizes microbial growth. The cooling conditions for different fruits and vegetables depend on the type, maturity, and cultivar. The most common cooling methods are water cooling, vacuum cooling, and air cooling.

16.2.3.1 Water cooling

In water cooling or hydro cooling, fruits and vegetables are immersed in cold water, which is usually in the bulk bins or flumes for transporting fruits and vegetables from the truck to the next processing step. This cooling method can be used for stem vegetables, leafy vegetables, and small fruits, such as peas, carrots, asparagus, tomatoes, melons, and peaches. However, some fruits and
vegetables, such as strawberries, cannot be cooled by cold water since more water on the surface increases the risk of microbial spoilage (Aked, 2002). Water cooling produces uniform cooling and there is no weight loss from dehydration; however, it produces a lot of waste water and there can be a high risk of microbial contamination in the cooling water. Sanitation, such as chlorination, of the water is often used to prevent contamination of the fruits and vegetables.

16.2.3.2 Vacuum cooling
Vacuum cooling is one of the most rapid cooling methods, providing uniform cooling using a vacuum chamber. The pressure around the fruits and vegetables is decreased, decreasing the boiling point of water. The heat in the fruits and vegetables is absorbed by the surface water as it evaporates. This method is used for cooling fruits and vegetables that have a large surface area to volume ratio, such as spinach, cabbage, lettuce, and other leafy vegetables. Vacuum cooling can cause up to 3% moisture loss in the product but water sprayed on the surface of fruits and vegetables before cooling can help reduce the loss of water during cooling (Aked, 2002).

16.2.3.3 Air cooling
Air cooling cools fruits and vegetables by heat transfer from the product to cold air circulating at −1°C to 16°C with a relative humidity (RH) of 85–90%. This step can also be done with room temperature air. Air cooling is efficient for cooling tomatoes, apples, and cherries. This cooling method requires an intermediate investment cost and the system is easy to control; however, air cooling takes more time when compared to other methods. The rate of cooling can be improved by using forced air, where the cold air is forced with a pressure gradient into the chamber or container (Aked, 2002).

16.2.3.4 Tomato cooling
After harvesting, tomatoes need to be cooled to remove field heat, increase shelf life, and preserve quality. Ripe tomatoes for fresh consumption are cooled down within 12 h of harvest to 7–10°C at RH 90% using forced air cooling. Tomatoes for processing are flume cooled to room temperature (Narayanasamy, 2006).

16.2.3.5 Apple cooling
The postharvest cooling of apples removes field heat, prolongs shelf life and reduces respiration. Within 12 h of harvest, apples are cooled down by either forced air cooling or hydro cooling at −1°C to 4.5°C with RH of 90–95% (Narayanasamy, 2006).

16.2.4 Peeling
Peeling is a critical step in the processing of many fruits and vegetables to remove undesirable parts which are either inedible or difficult to digest, and to enhance the physical appearance of the product. Efficient peeling methods remove minimal skin to produce a clean and undamaged surface. They should also use minimal energy and labor, and have low operating costs. The main methods for peeling fruits and vegetables are lye peeling, steam peeling, and mechanical peeling.

16.2.4.1 Lye peeling
Lye or caustic peeling applies a solution of lye (sodium hydroxide) at 10–20% at 100–120°C for 2–6 min. During this process, the lye hydrolyzes the pectin, loosening the skin, and a high-pressure water spray with rubber disks or a perforated mesh cage is then used to remove the skin. The average product loss during this peeling method is 17% (Fellows, 2000). Lye peeling can be used in the peeling of peaches, nectarines, apricots, pears, tomatoes, potatoes, apples, carrots, sweet potatoes, and onions.

Lye peeling produces waste water that contains a high organic load and high pH. Time in the lye, temperature of the bath, and concentration are the three major controllable factors that determine peeling efficiency. Increasing any of these factors increases the extent of peel removal. Time and temperature are linearly correlated, while time and concentration are correlated exponentially; therefore, longer time in the lye at higher lye concentration and higher temperature increases peel removal (Bayindirli, 1994).

16.2.4.2 Steam peeling
Steam peeling is the application of high-pressure steam at 1500 kPa in a pressure vessel to peel fruits and vegetables (Fellows, 2000). It can be used in the peeling of beets, potatoes, tomatoes, carrots, and onions. In steam peeling, peel removal is possible because of rupture of the cells just underneath the peel. Due to the high temperature and
pressure, the temperature of the water inside these cells exceeds the boiling point, but remains in a liquid state. When the pressure in the chamber is released, the water changes to steam, bursting the cells. Time, temperature, and pressure are the most critical factors to control to optimize the peeling process. The higher the temperature and pressure, the shorter the time required, and the more complete the peel removal. At higher temperatures, there is also less mushiness in the fruit due to cooking. The process uses relatively little water and produces little waste effluent; however, the peeling is less complete than in lye peeling. The waste peels that are produced can be used as fertilizer or animal feed or processed into other products, such as lycopene extract from tomato peeling (Knoblich et al., 2005).

16.2.4.3 Mechanical peeling
Mechanical peeling is mainly used for peeling fruits, such as apples, pears, pineapples, oranges, and other citrus fruits. Some vegetables can also be peeled by mechanical peeling, such as carrots, potatoes, and sweet potatoes. The most common mechanical peeling method uses either cutting tools (knife peeling) or an abrasive peeler. In knife peeling, the skin of fruits and vegetables is removed by either pressing stationary blades against the surface of fruits and vegetables, which are rotated, or rotating blades against the surface of stationary fruits and vegetables. In abrasion peeling of carrots, stiff brushes in a trough are used. In abrasion peeling of potatoes and sweet potatoes (Figure 16.8), the peelers have carborundum rollers or a rotating cylinder with an abrasive surface along the inner wall, which removes the skin of the product as the roller or cylinder rotates. The skin is then washed away. This method operates with low energy and capital costs and no heat damage occurs; however, the average product loss can be up to 25% (Fellows, 2000).

16.2.4.4 Tomato peeling
Tomatoes are typically peeled before further processing. The Food and Drug Administration (FDA) standard of identity does allow for canned, unpeeled tomatoes if the processor so desires. This is not common in the market, though there are some unpeeled salsas. This is probably because the peel is very tough and undesirable to the consumer; in addition, unpeeled tomatoes would show many blemishes that are hidden from the consumer by peeling. Some easy-peel varieties have been bred that may be suitable for canning with the peel on, since the peel is less tough. However, these varieties also have less resistance to insect and microbial attack on the plant and so are not typically used by growers.

There are two commonly used peeling methods for tomatoes: steam and lye. In California, most peeling is done by steam, while in the Midwest United States and in Canada, peeling is done with a hot lye solution. In steam peeling, the tomatoes are placed on a moving belt one layer deep and pass through a steam box in a semi-continuous process. Steam peeling is done at 165.5–186.2 kPa, which equals about 127°C, for 25–40 sec.
In lye peeling, the tomatoes pass on a conveyor belt under jets of hot lye (sodium hydroxide) or through a lye tank in a continuous operation. The tomatoes go through a solution of 12–18% lye at 85–100°C for 30 sec, followed by holding for 30–60 sec at room temperature to allow the lye to react. The lye dissolves the cuticular wax and hydrolyzes the pectin. The hydrolysis of the pectin in the middle lamella causes the cells to separate from each other, or rupture, causing the peel to come off (Bayindirli, 1994).

Lye peeling typically produces a higher yield of well-peeled tomatoes than steam peeling, but disposal of the lye waste water can be difficult. Steam gives a higher total tomato yield, but removes much less of the peel than lye. A 65% peel removal is considered good for steam peeling, while peel removal with lye is close to 100%. For this reason, lye is used exclusively in the Midwest United States, where peeled tomatoes are the most important tomato product.

After either steam or lye peeling, the tomatoes pass through a series of rubber disks or through a rotating drum under high-pressure water sprays to remove the adhering peel. Fruits with irregular shape and wrinkled skin are difficult to peel and result in excessive loss during the peeling step. Thus varieties prone to these characteristics are undesirable. Overpeeling is undesirable because it lowers the yield, results in higher waste, and strips the fruit of the red, lycopene-rich layer immediately underneath the peel, exposing the less attractive yellow vascular bundles.

### 16.2.4.5 Potato peeling

In potato processing, peeling is a critical step before further processing. Potatoes can be peeled by the application of steam, lye, or mechanical methods. Peeling can also be done by hand or using drum-shaped mechanized knife peelers but these methods are time consuming and the loss of product is high. Abrasion or steam peeling are commonly used before canning, freezing, or dehydration. In steam peeling, potatoes are loaded in a pressure vessel, which is slowly rotated at 5–6 rpm, and steam is quickly flashed to the product and immediately removed after steaming to avoid overheating (Saravacos & Kostaropoulos, 2002). In lye peeling, potatoes go through an immersion (Draper) lye scaldor or a lye-spray scaldor. In the immersion lye scaldor, the peeling is achieved in a long tank with a capacity of approximately 20 tonnes/h. The lye-spray scaldor consists of a conveyor belt, which can move the product slowly. The hot lye solution is sprayed on the potatoes and the skin is finally removed with sprays of wash water.

In lye peeling, the tissue of potatoes is damaged and a heat ring is formed inside the potato; therefore, this type of peeling is not used for potato chips. Potatoes for chipping are peeled using an abrasive peeler. The peeling drum has carborundum on the inner surface to remove potato skin by abrasion and a water spraying unit is used to wash the potato skin from the drum. In an abrasive peeler with 100 kg/h capacity, the loss of product was approximately 6% and the peeling efficiency was 78% (Singh & Shukla, 1995).

### 16.2.5 Blanching

Blanching is the application of heat at 85–95°C for a few minutes, depending on the product, to inactivate enzymes in some fruits and vegetables before processing. The other reasons for blanching are reducing surface microbial load, removing intercellular gases, preheating the materials, softening the product, and stopping respiration and maturation. Enzymes that cause quality loss and changes in fruits and vegetables include lipoxygenase, polygalacturonase, and polyphenol oxidase. Peroxidase is a heat-resistant enzyme found in most vegetables, which is frequently used as a marker enzyme to indicate whether the products are correctly blanched. There are two common blanching methods used commercially: steam and hot water. The fruits and vegetables are rapidly heated by steam or hot water immersion to a preset temperature and then, depending on the next step, may be cooled to ambient temperature. The blanching time depends on several factors, including size and type of product, heating method, and blanching temperature.

#### 16.2.5.1 Green bean blanching

Green beans are commercially blanched at 98–100°C by hot water for 3.5 min before further processing, usually in the production of frozen green beans, in order to inactivate enzymes, especially lipoxygenase which causes off-flavors from lipid oxidation (Lee & Smith, 1988). Unblanched frozen green beans develop off-flavors after 4 weeks of storage while blanched products can be stored up to 9 months without significant off-flavors (Katsabaxalis & Papanicolaou, 1984; Stone & Young, 1985).

#### 16.2.5.2 Apple blanching

Many fruits are not blanched during processing because of texture damage. However, apples are generally blanched
before canning, freezing, or dehydration to inactivate the enzymatic browning activity of polyphenol oxidase and soften the texture, especially in the production of apple sauce and apple pie filling. During blanching, apples are either passed through a steam tunnel or immersed in hot water at 77–93°C for 3–10 min (Arthey, 1997).

### 16.2.6 Size reduction

Size reduction decreases the average size of the pieces of the fruit or vegetable by cutting. Besides consumer demand and standard of identity, size reduction of fruits and vegetables before thermal processing decreases the thickness of the products, increasing the efficiency and rate of heat transfer during freezing, drying, and heating. In fruit and vegetable processing, methods of size reduction include chopping, cutting, slicing, and dicing, depending on the specific requirement of the processing technology. The equipment for size reduction includes slicers, dicers, shredders, and bowl choppers, depending on the preferred size of the final products.

#### 16.2.6.1 Tomato size reduction

During the production of salsa, tomatoes are diced by rotating blades, which slice the fruits first and then cut them into strips. The second rotating blades then cut the strips into cubes or dices (Figure 16.9). In the production of chilled sandwiches, tomatoes are sliced using high-speed slicers, which hold the fruit against the slicer blades by centrifugal force.

#### 16.2.6.2 Potato size reduction

Potatoes are usually cut in one plane to produce slices for making potato chips. In the production of French fries, potatoes are cut in two planes to produce strips. Potato slices for drying and frying are often rinsed in water before further processing. The rinsing stops polyphenol oxidase activity and minimizes black specks from burnt starch, as well as separating the slices from each other and from the equipment. The period of rinsing after slicing can be 10 to over 120 sec (Wicklund & Ivers, 1981).

### 16.2.7 Freezing

Freezing reduces the temperature of fruits and vegetables to below the freezing point of the product. This lowers water activity, slows down enzymatic reactions, and stops microbial growth. Ice crystal formation during freezing can damage texture. Many fruits and vegetables have to be blanched before freezing in order to reduce microbial load and stop enzymatic activity, especially enzymatic browning by polyphenol oxidase (PPO) and lipid

![Figure 16.9](image.png)

**Figure 16.9** (a) Tomato dicer. (b) Rotating blades inside the dicer. The first rotating blades slice and then cut tomato into strips. The second rotating blades cut the strips into cubes.
oxidation by lipoxygenase. Lipoxygenase is frequently the target of blanching in frozen vegetables since it causes the destruction of product quality, including producing off-flavors, undesirable odors, loss of carotene, chlorophylls, and essential fatty acids. However, it is difficult to analyze for lipoxygenase activity so peroxidase is analyzed as the target of blanching instead. Commercial frozen fruits and vegetables include strawberries, raspberries, spinach, peas, green beans, and potatoes.

There are two main types of freezers: mechanical and cryogenic. Mechanical refrigerators use cooled fluid, cooled air or cooled surfaces to remove heat from the product. Spiral blast freezers are the most common mechanical refrigerator in commercial freezing. In this freezer, cooled air at \(-30^\circ C\) to \(-40^\circ C\) is circulated over fruits and vegetables using a high velocity at 1.5–6.0 m/sec. The products are placed on a continuous spiral conveyor belt that passes through the freezing tower.

Plate freezers are also used in freezing fruits and vegetables. In this type of freezer, the products are placed in layers on plates, which are cooled to \(-40^\circ C\). Cryogenic freezers use liquid or solid carbon dioxide or liquid nitrogen, which directly contacts the product (Fellows, 2000). Plate freezers are used for prepackaged products in rectangular containers, while cryogenic freezing is not commonly used except for juices.

16.2.7.1 Apricot freezing

Apricots are frozen as peeled halves. Before freezing, either blanching or dipping the product in ascorbic acid solution is necessary to minimize browning due to polyphenol oxidase. The product is then packed in sugar or syrup at a 3:1 or 4:1 ratio of fruit to sugar prior to the freezing process. For freezing apricots, air-blast freezers are used and then the apricots are vacuum packaged to minimize color change. The storage of frozen apricots should be below \(-18^\circ C\) (Reid & Barrett, 2005).

16.2.7.2 Berry freezing

Many types of berries can be frozen either in syrup or as individual fruits. Before freezing, the berries are usually packed or dipped in 30–50% syrup as a barrier to oxygen and to protect flavor, color, and nutritional quality during freezing (FAO, 2005). The appropriate freezers are air-blast or cryogenic freezers. During freezing, the temperature of the freezer should be below \(-26^\circ C\), so that it takes less than 48 h for the center of the container to reach 0°C, and freezing should be maintained until the center temperature reaches \(-17^\circ C\). The storage of frozen berries should be below \(-18^\circ C\) (Reid & Barrett, 2005).

16.2.8 Dehydration

Dehydration increases the shelf life of fruits and vegetables by decreasing water activity, which is the available water for microbial growth and enzyme activity. Therefore, sufficient water removal can prevent microbial growth and undesirable enzyme activity. Dehydration removes water by evaporation, such as sun drying, tunnel drying, and freeze drying. Sun and solar drying are widely used to dehydrate fruits and vegetables around the world due to their simplicity and low cost. However, this method causes microbial contamination and some changes in quality, such as color and texture. It also requires a large amount of land and a hot, dry climate. Tunnel driers are commonly used for dehydrating fruits and vegetables in a short time. In tunnel driers, the products are placed on trays stacking on trucks, which continuously move through a tunnel. Freeze drying is a method developed for minimizing quality changes. This method removes water in fruits and vegetables by sublimation at low temperature along with low pressure to preserve the quality of the product; therefore, water in the products is changed into ice first and then changed directly from the solid into the gaseous state without becoming liquid.

16.2.8.1 Apple dehydration

Apples, with an original water content of 85%, are usually dehydrated at 55–75°C for 5–6 h in tunnel driers until the product has a moisture content of approximately 20%. To prevent both non-enzymatic and enzymatic browning of apples during drying and storage, apple pieces are treated in 8000 ppm sulfur dioxide for 1 min (FAO, 1995). Dipping in ascorbic acid (0.7%) can also be used to minimize enzymatic browning and increase vitamin C content in the final product.

16.2.8.2 Potato dehydration

After grading and washing, potatoes must be cooked completely prior to cutting and drying to preserve the flavor, color, and nutrition of the product. Dried uncooked potatoes are not acceptable due to their dark color and poor flavor. Water or steam cooking can be used to cook potatoes for approximately 20–40 min
(Shaw & Booth, 1983). During production of potato flakes, some antioxidants, such as butylated hydroxyanisole, are added to protect carotenoids (Baardseth, 1989).

16.2.9 Canning process

The canning industry uses thermal processing to ensure microbial safety and shelf life extension of food products. Retorting is a process that relies on the transfer of heat to guarantee the safety of canned food. In this process, cans are filled with the food product and then sealed hermetically before retorting. Wet heat and pressure are applied within the retort to sterilize both the container and food product. This heat sterilization is essential in canning, especially for low-acid foods, which have a pH greater than 4.6 and a water activity greater than 0.85, such as papaya, bananas, melons, corn, green beans, and peas. These foods provide appropriate conditions for some spore-forming microorganisms and anaerobic microorganisms, such as Bacillus coagulans and Clostridium botulinum, to grow. Therefore low = acid food requires more severe heat treatment, such as 121.1°C for 25 min for canning small carrots (FAO, 1995), than acid or acidified food (pH below 4.6 and water activity below 0.85), which can be canned at 100°C.

Many fruits are acid and have a pH below 4.6, such as apricots, grapefruit, pineapples, tomatoes, and peaches. A thermal process at temperatures at or below 100°C is used to destroy vegetative cells of spoilage microorganisms and inactivate enzymes. Hot-filling, a process of heating the juice with a heat exchanger to a fill temperature of 88–95°C, then filling the juice into a container, is also sufficient for acidic beverages, such as cherry, cranberry, and apple juice. The maximum pH of the fruit juice to be hot-filled is 4 and the shelf life of the product is between 9 and 12 months (Mclellan & Padilla-Zakour, 2005).

16.2.9.1 Tomato canning

Tomato products can be hot filled or processed in a retort as needed to minimize spoilage. Because tomatoes are a high-acid food with a pH of 4.0–4.5, they do not have to be sterilized. However, most tomato products undergo a retort process to ensure an adequate shelf life of 24–30 months. The continuous rotary retort is the most commonly used for tomato products. This retort provides agitation of the product and can handle large quantities in a continuous process. Because tomatoes are a high-acid food, a continuous rotary retort set at 104°C for 30–40 min is common. Exact processing conditions depend on the product being packed, the size of the can, and the type and brand of retort used. The key is for the internal temperature of the tomatoes to reach at least 88°C.

16.2.9.2 Potato canning

Since potatoes are a low-acid food, the required processing temperature is 115.6–121.1°C for 27–50 min, depending on the temperature, type of retort, and can size (FAO, 1995; Mishra & Sinha, 2011). Some commercial retorts include static retort, continuous retort, and hydrostatic pressure sterilization. Before canning, potatoes should be half-cooked using steam or boiling water to inactivate the enzymes and prevent discoloration.

16.2.10 Minimal processing

Many fresh fruits and vegetables are minimally processed to keep them fresh, prevent quality loss, and prolong shelf life. The shelf life of minimally processed fruits and vegetables is at least 4–7 days at 5°C. Commercial minimally processed products are ready-to-eat prepeeled, sliced, grated, or shredded fruits and vegetables, such as precut lettuce, grated carrot, and shredded Chinese cabbage for salad mixes. Minimal processing of fresh fruits and vegetables includes strict hygiene and good manufacturing practices, careful cleaning and washing before and after peeling, mild additives in washing, gentle peeling, cutting, slicing, or shredding, and a low temperature (usually below 5°C) during processing (Laurila & Ahvenainen, 2002).

In the production of minimally processed fruits and vegetables, packaging is an important factor that helps prolong their shelf life. Modified-atmosphere packaging (MAP) is one of the packaging methods used to reduce the respiration activity of the produce since it balances the levels of CO2 and concentration of O2 (generally at 2–5% for both gases) inside the package by using appropriate permeable packaging materials and/or a specific gas mixture in the package (Laurila & Ahvenainen, 2002).

16.2.10.1 Minimally processed potatoes

The minimal processing of potatoes is usually for prepeeled and sliced potatoes. The processing temperature is at 4–5°C. The main issue is browning so citric acid with ascorbic acid at a maximum of 0.5% for both, combined with 2% (w/v) calcium chloride, 4-hexyl resorcinol or sodium benzoate, is used during washing. After washing, the produce should be packaged immediately in a gas
mixture of 20% CO₂ and 80% N₂ in a package made of 80 μm nylon-polyethylene, which has an oxygen permeability of 70 cm³ m⁻² per 24 h, 101.3 kPa, 23°C, RH 0%. The produce should be stored in the dark at 4–5°C. The shelf life of prepeeled potatoes is 7–8 days and that of sliced potatoes is 3–4 days at 5°C (Laurila & Ahvenainen, 2002).

16.2.10.2 Minimally processed carrots

Minimally processed grated carrots are processed at 4–5°C. The optimal grate size for carrots is 3–5 mm. After grating, the product should be lightly sprayed with water and then mildly centrifuged to remove loose water. After centrifugation, grated carrots are packaging immediately with normal air in a package made of oriented polypropylene or polyethylene-ethylene vinyl acetate-oriented polypropylene, which has an oxygen permeability between 1200 and 5800 cm³ m⁻² per 24 h, 101.3 kPa, 23°C, RH 0%. The produce should be stored in the dark at 0–5°C. The shelf life of grated carrots is 7–8 days at 5°C (Laurila & Ahvenainen, 2002).

16.2.11 Sustainability

The major waste streams produced in fruit and vegetable processing are solid waste, from trimming and peeling, and waste water from washing, fluming, peeling, can washing, cooling, and clean-up. Table 16.2 shows the amount of waste water and solid waste produced in some fruit and vegetable industries. Waste management is beneficial not only to the environment, but also to the business, including reducing costs for waste treatment, decreasing resource consumption, and improving the reputation of the business. There are several methods of decreasing waste generation and improving waste management, such as recycling and reuse of materials, improving raw material management, and employee training.

Waste water from the fruit and vegetable industry can be categorized into low-polluted (wash water) and high-polluted (process water) waste. Low-polluted waste has a biological oxygen demand (BOD) of less than 200 mg/L while high-polluted waste has a BOD around 20,000 mg/L. Aerobic systems, such as aerated lagoons, are adequate to treat low-polluted waste. For high-polluted water, anaerobic biological treatment can be used with 70–95% efficiency (Tran, 2009).

Solid waste can be recycled or reused depending on its composition and properties. For example, pectin is recovered from peeled fruit skins and used in other food products. Waste materials containing cellulose can be fermented to sugar for production of organic acids, ethanol, and edible oils. Other fruit and vegetable solids are commonly used as fertilizers or animal feed.

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<thead>
<tr>
<th>Table 16.2 Amount of waste water and solid waste produced in some fruit and vegetable industries</th>
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<tr>
<td><strong>Product</strong></td>
</tr>
<tr>
<td>Carrots</td>
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<td>Canned corn</td>
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<td>Canned peas</td>
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<td>Frozen potato</td>
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<tr>
<td>Canned peaches</td>
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<td>Pears</td>
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