Processing of Fruit and Vegetable Beverages

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15.1 Introduction

15.1.1 Classification and regulations

In 2011, world fruit production was 638 million metric tonnes (MT). China, India, Brazil, USA, Italy, Indonesia, and Mexico are the largest producers, accounting for 51% of the world production (FAO, 2010). An important portion of fruit production is processed into juice, but data on processed juice processing are readily available for only a few countries. Table 15.1 summarizes the production of the major fruits used for processing of juices and nectars in the world; the third column of Table 15.1 shows the 2010 sum of the production of fruit by the five largest producers of each of the fruits. These fruits were selected because they are typically used for juice processing. Juices are defined as mechanically extracted juices from fruits or vegetables to which no water or other exogenous substances are added. Juices are commercialized as single-strength or concentrates, as 100% from a particular fruit or, less often but increasingly commonly, as blends (CODEX STAN 247-2005).

Not-from-concentrate (NFC) juices (sometimes labeled as “premium”) typically retain more of a fresh-like quality compared to reconstituted juices that undergo longer thermal treatments and handling steps that affect color and flavor. Soluble solid content (SSC) and titratable acidity (TA) of both NFC and reconstituted juice must fall within the range of what results from extracting the juice from a mature fruit. These ranges are often regulated and regulations differ slightly in different parts of the world.

Adjustment of reconstituted juice quality is achieved by proper dilution. NFC products are adjusted by blending juices extracted from fruits with different levels of maturity. Storage and transportation of NFC are more costly than for reconstituted juices; therefore, consumers also have to pay a premium. Table 15.2 shows the total imports and exports for main fruit juices in the US. Figure 15.1 shows the average annual consumption of orange and apple juice, as well as the total citrus and non-citrus juice consumption in the US in the last three decades. Orange juice is the most consumed fruit juice (56–62%) but its consumption has declined compared to apple, which has increased from 18% to 26% in the last three decades. Both juices combined account for 80% of the total fruit juice consumed in the US.

“Nectar” typically refers to beverages produced by dilution of fruit pastes or juices with or without the addition of sweeteners. Nectars are commercialized as from a single fruit or as blends. In some countries, e.g. the UK, a fruit beverage labeled “nectar” must contain at least 25–50% fruit juice, depending on the specific fruit (SI 2003/1564). Fruit drinks are beverages with a small content of juice.

In the US, any beverage containing fruit juice must be labeled with the percent juice content. Beverages containing less than 1% juice must also be labeled as such (21 CFR...
Several countries that do not have their own definitions or standards typically adopt those of the Codex Alimentarius (CODEX STAN 247-2005), the EU, or the US standards. In addition to standards of identity, juice and nectar labeling and trade are regulated in some countries and in some cases on the basis of country of origin. This is quite controversial, because to maintain quality year around, often fruit juices from different origins need to be blended. In the case of blends of juices from different fruits, it becomes impossible to establish a single country of origin. Beyond labeling, processing of fruit juices is regulated, in particular to ensure safety. In the US, the Food and Drug Administration (FDA) has mandated that Hazard Analysis and Critical Control Point (HACCP) plans be implemented in all juice and fruit paste processing plants (21 CFR 120; Goodrich et al., 2008).

Table 15.1 Production of fruit for processing into commercial juices and nectars in 2010 with data from FAO (2010)

<table>
<thead>
<tr>
<th>Fruit/vegetable</th>
<th>Growing regions</th>
<th>Total fruit production from the 5 world largest producers (MMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Juices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>Subtropical/tropical</td>
<td>41.9</td>
</tr>
<tr>
<td>Apple</td>
<td>Temperate/subtropical</td>
<td>44.4</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>Subtropical/tropical</td>
<td>5.0</td>
</tr>
<tr>
<td>Mandarin/tangerine</td>
<td>Subtropical/tropical</td>
<td>14.6</td>
</tr>
<tr>
<td>Lemon/lime</td>
<td>Subtropical/tropical</td>
<td>8.2</td>
</tr>
<tr>
<td>Pineapple</td>
<td>Tropical</td>
<td>9.7</td>
</tr>
<tr>
<td>Grape</td>
<td>Temperate</td>
<td>34.6</td>
</tr>
<tr>
<td>Pear</td>
<td>Temperate/subtropical</td>
<td>17.9</td>
</tr>
<tr>
<td>Tomato</td>
<td>Temperate/subtropical</td>
<td>85.4</td>
</tr>
<tr>
<td>Pomegranate</td>
<td>Semi-arid, mild temperate, subtropical</td>
<td>Not reported</td>
</tr>
<tr>
<td>Cranberry</td>
<td>Temperate, moist</td>
<td>0.4</td>
</tr>
<tr>
<td>Coconut water or milk</td>
<td>Tropical</td>
<td>52.0</td>
</tr>
<tr>
<td><strong>Nectars</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mango/mangosteen/guavas</td>
<td>Tropical</td>
<td>26.7</td>
</tr>
<tr>
<td>Guava</td>
<td>Tropical/subtropical</td>
<td>Included in Mango</td>
</tr>
<tr>
<td>Peach/nectarine</td>
<td>Temperate/subtropical</td>
<td>15.1</td>
</tr>
<tr>
<td>Apricot</td>
<td>Temperate/subtropical</td>
<td>1.7</td>
</tr>
<tr>
<td>Passion fruit</td>
<td>Tropical/subtropical</td>
<td>Not reported</td>
</tr>
<tr>
<td>Papaya</td>
<td>Tropical/subtropical</td>
<td>8.6</td>
</tr>
<tr>
<td>Guanávana</td>
<td>Tropical</td>
<td>Not reported</td>
</tr>
<tr>
<td>Strawberry</td>
<td>Subtropical</td>
<td>2.3</td>
</tr>
<tr>
<td>Banana</td>
<td>Tropical</td>
<td>65.8</td>
</tr>
<tr>
<td>Tamarind</td>
<td>Tropical</td>
<td>Not reported</td>
</tr>
<tr>
<td>Plum</td>
<td>Temperate</td>
<td>7.5</td>
</tr>
</tbody>
</table>

MMT, million metric tonnes.

Table 15.2 Volume of US imports and exports of selected juices to and from the rest of the world, with data from USDA-ERS for 2010 (ERS, 2010)

<table>
<thead>
<tr>
<th>Fruit juice</th>
<th>Volume in millions of liters SSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Imports</td>
</tr>
<tr>
<td>Apple</td>
<td>2182</td>
</tr>
<tr>
<td>Grape</td>
<td>184</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>2</td>
</tr>
<tr>
<td>Lemon</td>
<td>98</td>
</tr>
<tr>
<td>Lime</td>
<td>49</td>
</tr>
<tr>
<td>Orange</td>
<td>1150</td>
</tr>
<tr>
<td>Pineapple</td>
<td>255</td>
</tr>
<tr>
<td>Wine</td>
<td>932</td>
</tr>
</tbody>
</table>

SSE, single strength equivalent.
15.1.2 General processing operations

All juice processing lines have several unit operations in common. A general flow process diagram (FPD) for juice production is shown in Figure 15.2. Fruit composition, geometry, and other physical properties dictate the method of juice or nectar extraction and defect removal, as well as the need for peeling prior to extraction or the inclusion of deaeration and other secondary operations. Relative to other goods, the profitability of most processed foods, including fruit and vegetable beverages, is based on large volumes with small profit margins. Also, consumers are increasingly informed and concerned about nutrition and health with the general perception that the closer to fresh, the better a product is. Therefore, it is critical to minimize the extent of processing and product losses in the system.

Contrary to common belief, juices are often pasteurized more than once, subjecting the product to thermal abuse. A typical example of this is depicted in Figure 15.2. For example, in the production of juice blends, juices and nectars are pasteurized after extraction and again after blending or ingredient addition and prior to packaging. In the case of orange juice, often the juice is stored for a long period of time between the first pasteurization and packaging. In such cases, a second pasteurization is also needed before packaging. In many cases, blending occurs at locations different from where juices or fruit pastes are produced. To minimize thermal abuse, two major strategies are employed: aseptic processing and non-thermal processing. Both represent an additional cost and are not always economically viable.

15.2 Juices

15.2.1 Citrus

15.2.1.1 Growing regions, cultivars, world production, major producers, and processors

Citrus cultivars commercially used for the production of beverages include sweet orange (*Citrus sinensis*), which is the most abundant, grapefruit (*Citrus paradisi*), mandarin (*Citrus reticulata*), lemon (*Citrus limon*), Persian lime (*Citrus latifolia*) and Key or Mexican lime (*Citrus aurantifolia*). The earliest reports of citriculture in China, where most likely citrus originated, date from 2200 BC (Zhaoling, 1986). In about 400–300 BC, after spreading throughout Asia, citrus was introduced to Europe. In the 1500s citrus was introduced to the Americas. Between the 1700s and late 1800s citrus spread to western US and Mexico.

The major citrus production is located within the tropical and subtropical regions of the world; that is, between latitudes 40ºS and 40ºN, also called the world citrus belt. However, in subtropical regions, between 20º and 40ºN and S, defined seasons with cool nights and alternate rain and drought result in longer maturation periods, higher sugar accumulation, and better fruit quality. Figure 15.1 shows the consumption of orange, citrus, apple, and non-citrus juices in the US in the last three decades. In 2010, US consumers drank on average 13 L/yr of orange juice, accounting for 50% of the total juice consumption in that country (USDA-ERS, 2011).
15.2.1.2 Harvest and handling for processing

Each citrus cultivar has a different harvesting period. Several orange varieties are used to ensure almost year round availability for processing. In the northern hemisphere, oranges are harvested between October and June, in the southern hemisphere between June and February. The most commonly utilized varieties of oranges for processing are Valencia, Hamlin, Pineapple, and Ambersweet. Hamlin oranges are harvested from mid-fall to mid-winter (October to January in the northern hemisphere (NH)), Pineapple and Ambersweet are harvested mid-winter to early spring (January to March in the NH) and Valencia, the most abundant variety, is harvested during the spring and early summer (March to June in the NH). There are two types of grapefruits, white and colored (pink or red). The best known white varieties are Duncan and Marsh, and the colored varieties are Redblush and Star Ruby. Mature grapefruit can be harvested from mid-fall to mid-spring. Mature fruit can remain on the tree for that period of time. Because of its bitterness, the market for white grapefruit juice has been largely replaced by red grapefruit juice. Tangerines or mandarins are mostly used for the fresh market but in the US, up to 10% of tangerine juice can be added to orange juice without having to label it. This practice is mainly done to improve color of juice from early season varieties. In contrast to orange and grapefruit, where juice is the main product, lemon and lime juices are the by-products, while peel oil is the most valuable and main product.

Although mechanical harvesting machines are commercially used, in the US, most oranges or grapefruits
are harvested by hand. The harvested fruit is dumped into trucks that carry approximately 20 MT to the processing plants. Fruit is unloaded by tilting the trucks on concrete or hydraulic ramps and is pregraded while it is conveyed into large vertical storage bins. Storage bins are designed with alternating baffles at an angle that prevent the fruit from bruising during bin loading and also to prevent fruit in the bottom of the bin from being crushed by the weight of the fruit on the top. Representative samples of each truck load are taken to assess fruit quality. Fruit from bins is washed, culls are removed often by hand and the fruit is sized before extraction.

15.2.1.3 Process description (Figure 15.3)

15.2.1.3.1 Juice extraction and finishing

There are two main juice extractor manufacturers, John Bean Technologies Corporation (JBT) and Brown International Corporation LLC. Detailed information on these extractors is given in the websites of the two companies:
- www.jbtfoodtech.com/solutions/equipment/citrus-juice-extractor.aspx

Briefly, in Brown extractors, fruit is loaded into a carousel made of a set of hemispherical cups that hold the fruit while a blade cuts it into two pieces. The cups spread apart while retaining half of an orange each. Then, a spinning reamer presses the half-orange against the cup to extract the juice. Pressure and gap between reamer and cup are among the critical adjustment parameters in Brown extractors. Each extractor can handle 4–14 tonne/h of fruit.

John Bean Technologies extractors are typically configured with three, five or eight cups, with five cups being the most common. Cups are made of a hard cast stainless steel alloy and are formed by an array of rigid “fingers” that join at the bottom of the cup with an orifice at the center. Fruit is fed onto the lower cups and then pushed downwards with the upper cup. As the fruit is pushed, the peel

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**Figure 15.3** Flow diagram of orange juice and orange by-product processing. Mass balance values are approximate as they vary depending on processing conditions. Reproduced from Reyes-de-Corcuera et al. (2012), with permission from John Wiley & Sons, Inc.
so-called flavor packs produces more uniform quality added back to juice before packaging. Addition of the separate and concentrate flavor fractions that are then sold to flavor companies that, by physical means only, oil is reincorporated to concentrate and another part is recovered to recover 100% cold-pressed oil. Part of this cold-pressed is anted to recover an oil-rich phase that is then centrifuged. Oil emulsion is recovered and dec-

are immersed in a shallow vat with water, where the oil blades that puncture the fruit peel. The puncturing rollers convey into rollers with thousands of small, sharp (BOEs) are placed before extractors. Whole oranges are conveyed through the back of the extractor. Brown oil extractors the peel, forming an oil-in-water emulsion that drains oil glands are burst. A manifold of water nozzles sprays of the orange, it is shredded and pressed and thus, the yield and produces a drier pulp but reduces juice quality because pulp particles are extruded through the finisher mesh and bitter compounds formed in the pulp are released into the juice. Some processors use a cyclone between extractors and finishers to remove defects such as embryonic seeds. Defect removal is particularly impor-

tant when pulp is intended to be sold as a by-product.

15.2.1.3.2 Essential oil

In JBT extractors, as the peel is separated from the rest of the orange, it is shredded and pressed and thus, the oil glands are burst. A manifold of water nozzles sprays the peel, forming an oil-in-water emulsion that drains through the back of the extractor. Brown oil extractors (BOEs) are placed before extractors. Whole oranges are conveyed into rollers with thousands of small, sharp blades that puncture the fruit peel. The puncturing rollers are immersed in a shallow vat with water, where the oil emulsion is formed. Oil emulsion is recovered and de-

anted to recover an oil-rich phase that is then centrifuged to recover 100% cold-pressed oil. Part of this cold-pressed oil is reincorporated to concentrate and another part is sold to flavor companies that, by physical means only, separate and concentrate flavor fractions that are then added back to juice before packaging. Addition of the so-called flavor packs produces more uniform quality products. Because all the components of the flavor pack are from orange, after pack addition the final concentration of oil in juice is typically below 0.04% and only a small fraction of that amount is responsible for the aroma of the juice, so it is labeled 100% orange juice. This has recurrently produced controversy among some consumers, who perceive that addition of such oils is “artificial” and argue that the same concentrations of flavors would not be present in freshly squeezed orange juices. The rest of the cold-pressed oil is sold to other industries.

15.2.1.3.3 Pulp recovery

Pulp refers to burst juice vesicles. The market for orange pulp has increased in recent years. Some pulp is added back to juice to produce what is marketed as “home style” or “country style.” A very large portion of pulp is sold to the Asian and European markets to provide mouthfeel and the perception of a fresher, more natural product to other fruit-based beverages. Figure 15.4 shows the schematic representation of a pulp recovery system. After separation of defects in a hydroclone, pulp is recovered at approximately 500 g/L. This measurement of pulp concentration is on wet basis and is based on an empirical test commonly used in the industry (Kimball, 1999). An instrument based on nuclear magnetic resonance (NMR) is also used, mostly by large processors. Pulp is then pasteurized and finished to increase pulp concentration to approximately 900 g/L, packaged, and frozen.

Some processing plants pasteurize 900 g/L or more concentrated pulp for aseptic filling. Pulp at such high concentrations behaves like a paste that displays wall slippage (Payne, 2011). At flow rates encountered in the industry, flow is laminar and heat transfer from tubular heat exchangers occurs mostly by conduction. Therefore, to maximize temperature uniformity, small pipe diameters and static mixers are used. The main issue of this approach is the enormous pressure drop and associated pumping costs. For that reason, some manufacturers prefer to produce frozen pulp. The size and integrity of pulp vesicles are of great importance to processors. Both parameters affect the ability of pulp to float and consumer sensory perception. Monitoring and controlling the extent of pulp vesicle degradation, i.e. tearing and size reduction, is critical as it affects quality of the end-product and the total amount of pulp that needs to be added back to the juice or to any beverage to produce the right balance of floating and sinking pulp. One must keep in mind that unit operations that involve high shear stress affect pulp quality.
15.2.1.3.4 Frozen concentrate orange juice

Frozen concentrate orange juice (FCOJ) was developed in the mid-1940s to provide a good source of vitamin C to US allies after World War II. The main rationale behind concentration was to reduce the cost of transportation. By 1970, it represented 78% of the US orange juice market. Today the market share for FCOJ is only about 8%, due to strong marketing efforts for NFC and reconstituted orange juice. A detailed historical description of the evolution of the orange juice market has been published recently (Morris, 2010).

Orange juice is concentrated from 12ºBx to 65ºBx in thermally accelerated short-time evaporators (TASTE). TASTE systems are 5–7 effect falling film evaporators. The capacity of these evaporators ranges from 14,000 to 91,000 kg/h of evaporated water. At the last stages of evaporation (40–45ºBx), juice is often homogenized to reduce viscosity and facilitate flow of product. Figure 15.5 shows the schematic representation of a five-effect, five-stage TASTE in mixed configuration. In this configuration, single-strength juice is fed to the third effect, which operates at a lower temperature than the first and second effects. Hence, aroma compounds that are recovered there experience less thermal degradation. Because during evaporation the juice is stripped from all aroma volatile compounds, essence oil and aqueous aroma must be added back to FCOJ. Approximately 0.01% cold-pressed oil is added to the concentrate and it is chilled to −9°C. The headspace of FCOJ tanks is flushed with nitrogen to remove oxygen and to minimize oxidative reactions that affect vitamin C and flavor during storage. FCOJ tanks are kept cold in refrigerated rooms. Large processing plants have over 76,000 m³ storage capacities for 65ºBx concentrate. Concentrate can also be stored in 200 L drums. Concentrate is marketed as reconstituted juice (12ºBx) packaged in half-gallon or 1 gallon containers, as 40ºBx, distributed to food service businesses, or as 40ºBx, 8 oz cans, to be sold at grocery stores and reconstituted by the consumer.

15.2.1.3.5 Pasteurization

Microbial inactivation

Most disease outbreaks in orange juice have been caused by *Salmonella* spp. (Danyluk et al., 2012). Several of these outbreaks were associated with unpasteurized orange juice. Therefore *Salmonella* is the recommended pathogen of interest for the purpose of pasteurization. *Escherichia coli* O157:H7 can grow in fruit juices with pH greater than 4. Therefore, although no *E. coli* O157:H7 outbreaks have been reported, in late season fruit and under poor sanitation conditions, this bacterium is a potential hazard. *Alicyclobacillus* spp. have been found in orange juice. This spoilage microorganism does not typically affect refrigerated juices because vegetative cells are killed during pasteurization and spores do not germinate at low temperatures. However, it can affect the quality of shelf-stable products and its presence impacts the ability to export. Lactic acid bacteria such as *Lactobacillus* and *Leuconostoc* have also been reported to affect orange juice quality (Rushing et al., 1956).
Figure 15.5 Schematic representation of a pilot-scale five-effect, five-stage TASTE. Top right corner, schematic of the cross-section of the top of stages 1 and 3. CH, chiller; EC, essence cooler; EFF, effect; FC, essence recovery; PH, preheater; SP, separator; STG, stage. For color details, please see color plate section.
Enzyme inactivation
Orange juice pasteurization aims not only to kill pathogenic and spoilage microorganisms, but also to inactivate pectinmethyl esterase (PME). PME catalyzes the de-esterification of methoxy groups of pectin, which in turn, and especially in the presence of divalent cations, form soft gels that favor the precipitation of the juice cloud. Orange juice pasteurization conditions are adjusted to achieve PME inactivation because PME is more heat resistant than the pathogens of interest. The time-temperature profile for pasteurization is typically 85–90°C for 10–15 sec. Pulpy orange juice is pasteurized in tubular pasteurizers. Plate heat exchangers are occasionally used when pulp content is low because pulp fouls conventional plate heat exchangers. Because PME is mostly bound to pulp particles, physical removal of pulp by finishing or centrifugation decreases the PME activity in the juice.

Of all non-thermal pasteurization and enzyme inactivation technologies that have been widely researched in orange juice, to the best of our knowledge, only high hydrostatic pressure is used commercially. Challenges associated with early designs that directly pressurized juices included keeping the product aseptic after depressurization, the cost of operation and maintenance, and safety concerns. New systems that pressurize juice filled and sealed bottles with water appear promising. A main challenge is the inactivation of endogenous enzymes that often require higher pressures and longer processing times than the pathogen of interest. Also, because of the batch nature of the process, this technology is only viable for small quantities of premium products.

15.2.1.4 Product quality
Flavor is arguably the most important quality aspect of any juice, but it is quite complex, as it depends on the physical properties of the juice such as viscosity and pulp presence, as well as on the composition of non-volatile and volatile compounds. Routinely measured quality parameters in orange juice are soluble solid content (SSC), SCC to titratable acidity (TA), expressed as percent citric acid or Bx/acid ratio (BAR), color, cloud, pulp content, and vitamin C content. The concentration of oil in juice is also determined by titration, as percent d-limonene. The maximal appropriate concentration is 0.04%. Above that concentration, most consumers experience a burning sensation on the lips and mouth. Of that 0.04%, only about 5% contains the aroma active volatiles. Compounds responsible for characteristic orange aroma include terpenes, aldehydes, ketones, alcohols, esters, and organic acids. Aldehydes level is used as an indicator of relative quality, with decanal and octanal as the most abundant. Detailed reviews of aroma compounds have been published elsewhere (Maarse & Visscher, 1989). Flavor may be negatively impacted by limonin, a bitter compound present in the seeds. Limonin is also formed after extraction in juice from Navel oranges. This juice needs to be debittered, typically by adsorption with resins.

Thermal pasteurization of orange juice affects mostly vitamin C, α-carotene, β-carotene, β-cryptoxanthin, and vitamin A. Other vitamins, as well as carbohydrates, lipids, amino acids and minerals, are not significantly affected by processing. The presence of dissolved oxygen also affects flavor, color, and vitamin C content. For that reason, prior to pasteurization, orange juice is often de-aerated. Single-strength and concentrate juices are stored in tanks with the overhead space filled with nitrogen gas to minimize the reincorporation of oxygen. For the same reason, orange juice is bottled leaving a minimal headspace volume. Some processors also dispose headspace oxygen with nitrogen to maximize shelf life. Oxygen permeability of packaging materials is critical.

15.2.1.5 Sustainability
In the last 20 years, the orange juice industry in the US has experienced a strong consolidation. Most small companies were acquired by larger ones or closed in the face of competition based on economy of scale. Fourteen processors are members of the Florida Citrus Processors Association. To remain competitive, most plants have systems for by-product recovery, water recycling, and/or reduction of emissions of volatile organic compounds. By-products not mentioned above include dried peel, also called “dried pulp,” which should not be confused with juice vesicles. Pulp is shredded, hydrolyzed, pressed, and dried in rotary drums. Press liquor that is recovered after peel pressing can be concentrated using the waste heat from the drier and a multiple effect waste heat evaporator (WHE). A fraction of the molasses is recirculated to the pressed peel to increase the percent dry matter and improve the efficiency of the drying operation. Citrus peel molasses are also fermented to produce food-grade alcohol. D-limonene from the peel is recovered as well. It finds markets as a solvent in the electronic component manufacture, for paints and other household products. The dried peel is pelletized and sold as cattle feed. Peel dryers are operated by burning fuel by direct or indirect exposure to the combustion gas. The economic viability
of this operation is directly related to the oil prices and alternative cattle feed prices, which is in many cases tied to the supply of corn. A very small portion of orange peel is also used for marmalades or dried spice.

From an environmental perspective, citrus processing plants have proactively integrated the reuse of water to minimize waste water. Modern plants operate steam with almost full return of condensate to the boiler. Similarly, cooling towers are operated at high efficiency. Condensate water from the FCOJ evaporator is used to wash incoming fruit or other parts of the plant. Waste water is treated to decrease the biological oxygen demand to a level where it can be used for agricultural field irrigation. The WHE and the cold storage of very large volumes or NFC or FCOJ account for most of the energy consumption in a citrus processing plant. Some processing facilities have co-generation plants that reduce electrical consumption from the grid. Citrus by-products have been comprehensively discussed elsewhere (Braddock, 1999).

15.2.2 Apple

15.2.2.1 Growing regions, world production, and major producers

Apple is the second most consumed fruit juice in the world, with total export value of single-strength and concentrated juice of US$3936 million in 2009 (FAO, 2010). The apple species, *Malus pumila*, originated in southwestern Asia and Europe and was brought to the Americas by European colonists.

The major apple production is located within the temperate regions of the world; that is, between latitudes 35º and 50ºN, and between latitudes 30º and 45ºS. China, the US, Turkey, Poland, and Iran are the largest apple producers, accounting for over 70% of the world production in 2009. In the US, apple acreage is a little over one half that of orange, with Washington, Michigan, New York, and California as the major producers. In 2010, of the utilized US production, 14.5% was processed into juice. There are hundreds of apple cultivars but some of the most common include Red Delicious, Golden Delicious, McIntosh, Rome, Beauty, Granny Smith, Fuji, and Braeburn. In China, the most popular varieties are Fuji (45%), New Red Star (12%), Qinguan (10%), and Guoguang (10%) (O’Rourke, 2003). Dynamic development of new cultivars and changing preferences are occurring around the world. In 2011, 394,400 MT of apples were processed into juice (AMS, 2011). In 2010 Americans consumed 8 L/yr of apple juice, accounting for 31% of the total juice consumption.

15.2.2.2 Harvest and handling for processing

Apples are harvested by hand and the large majority of apples are harvested for the fresh market. Mostly culls, in particular small apples or apples not suitable for other processed products such as slices or sauces, are used for juice processing. However, with the increased demand for apple juice, some apples are being harvested for juice processing. It is crucial to maintain fruit wholesomeness and ensure fruit maturity prior to processing to avoid contamination. In particular, postharvest spoilage microorganisms may contaminate the fruit during storage. Of particular concern are *Alicyclobacillus* spp., a group of acid-tolerant, spore-forming bacteria that resist thermal processing and whose spores germinate during storage of shelf-stable products. Although not posing a health threat, *Alicyclobacillus* spp. produce guaiacol, which has an unpleasant medicinal off-flavor.

15.2.2.3 Process description

Several books and book chapters on apple juice processing have been published in the past decades (Binnig & Possmann, 1993; Downing, 1989; Lea, 1995; Root & Barrett, 2005). Figure 15.6 shows a flow diagram of apple juice and apple by-product processing, with approximate mass balance.

15.2.2.3.1 Washing and sorting

Apples are typically dumped into tanks where they soak to loosen soil to facilitate downstream removal with rotating brushes. Washing is critical to remove molds and bacteria that may spoil the juice. Patulin, a mycotoxin, is of particular concern. Hence, fruit with signs of spoilages are either removed or cut to remove spoiled portions.

15.2.2.3.2 Maceration

Whole apples are then macerated using a hammer mill or a disintegrator to produce a slurry, called “mash” or “pulp.” The particle size and consistency of the mash depend on fruit variety and maturity and affect juice extraction yield. Juice is extracted by pressing the mash with a hydraulic, pneumatic, screw, or basket press. Some presses require press aids that minimize slippage and increase yield. Enzyme treatment with cocktails of PME, polygalacturonase and pectinlyase and cellulase are used to hydrolyze pectin and fruit cell wall, facilitating juice release during pressing and increasing yield. The catalytic activity and mechanism of action of these enzymes have been studied extensively. Enzyme treatment requires heating because it is most effective at around 50 ºC and requires some reaction time. However, press throughput
can be increased by up to 40% and juice yield increases by about 20% (Root & Barrett, 2005). Small amounts of enzyme are required (~100 mL/t), making this approach cost-effective. At 50 ºC some of the enzymes in the cocktail denature and lose activity. However, treatment at lower temperatures (~40 ºC) favors microbial growth, and even lower temperatures result in decreased enzyme activity. Therefore, enzyme cocktail formulations require a careful balance of kinetic activity and stability.

A complex enzyme cocktail with increased cellulase, hemicellulase, oligomerase and other enzyme activities is used for mash liquefaction. Addition of cellulases can increase SSC by almost 5%. Research and mining for heat-stable enzymes or for enzymes that are highly active at low temperature is under way. Enzyme catalysis at high pressure and temperature has also been proposed.

Another important consideration is the downstream use of the product and by-product. If pomace (solid residue after juice extraction) is to be used for pectin production, excessive pectin hydrolysis produces short galacturonic acid oligomers, losing the desired functional properties of the polymer. Residual activity also prevents gel formation when concentrate is used to produce jellies.

### 15.2.2.3.3 Juice extraction

Apple juice is extracted by pressing the mash in a belt, hydraulic, pneumatic, other type of press or a combination of presses. Typically, hydraulic presses are more efficient (3–5%) than their pneumatic counterparts. For liquefied mash, a decanting centrifuge is used. Juice yield is affected by pressing conditions (temperature, pressure, presence, and type of pressing aid) and by the quality of the mash, which in turn depends on the quality of the apples, particle size after maceration and extent of enzyme treatment. Typical juice yields range between 70% and 95%. Cellulose or rice hulls are often added (1–2%) as press aids that help to uniformly distribute pressure across apple particles that constitute the pulp and mash. Press aids can increase extraction yields by up to 10%.

### 15.2.2.3.4 Clarification

Most apple juice is clarified, although the market for cloudy, “country style” apple juice appears to be growing with the demand for more fresh-like, minimally processed food products. Most processors currently use pectinase
cocktails to clarify apple juice. Cleavage of pectin decreases juice viscosity, which facilitates filtration. Similar to maceration, a pectinase formulation is used for clarification and the conditions are also either 10–20 ºC for 8–10 h or 45–55 ºC for 1–2 h. The amount of enzyme formulation is adjusted by each processor but is in the range of 20–30 mL/m³ for liquid formulations. Although in many processes enzymes are a large portion of the processing costs, pectinases are relatively inexpensive. Unlike with citrus, addition of enzymes to apple and other clarified juices does not violate the standards of identity. Fining, that is, further removal of suspended colloidal particles by decanting, is facilitated by addition of positively charged gelatin or bentonite during or after enzyme clarification. The decanted juice is further clarified by filtration and/or centrifugation. There are different types of filters, including press (Figure 15.7), vacuum, and rotary filters. Filter aids commonly used are diatomaceous or cellulose. Continuous disk centrifuges (Figure 15.8) are typically used.

Because apples of many different varieties are used for juice production, blending is commonly done to produce uniform quality product.

15.2.2.3.5 Concentration
Apple juice concentration is done mostly by evaporation, although freeze concentration can be done. Apple juice is typically concentrated to 70ºBx in 4–5 effects. High-temperature, short-time (HTST) falling film evaporators that operate under high vacuum at 90–100 ºC are commonly used. Like orange, apple juice evaporators are operated in mixed configuration. Single-strength juice is fed to the second or third stage to separate volatiles at a lower temperature than if fed at the first stage. Aromas are recovered and concentrated by distillation. High temperatures are used to pasteurize the juice during evaporation to ensure sufficient microbial kill and avoid concentrate spoilage. Plate evaporators and rising film evaporators have also been used for apple juice concentration.

15.2.2.4 Relevant processing conditions
15.2.2.4.1 Pasteurization
Microbial inactivation
Yeast, molds, and bacteria are commonly found in apple juice. For the purpose of pasteurization, the US FDA recommends that \textit{E. coli} O157:H7 and \textit{Cryptosporidium parvum}, whichever is the most tolerant microorganism for any given pasteurization treatment, be considered as the pertinent microorganism for apple juice. As in citrus juices, \textit{Alicyclobacillus} spp., though not pathogenic, is of concern to the apple juice industry. This is particularly important because of the large production of shelf-stable apple juice. At room temperature, \textit{Alicyclobacillus} spores that are not destroyed during thermal treatment germinate and produce a strong medicinal off-flavor that is characteristic of guaiacol. Combined thermal and pressure treatments were reported to synergistically kill \textit{Alicyclobacillus} spores in apple juice concentrate (Lee et al., 2006). Yeasts and molds can spoil juice by fermenting it but the main concern in apple juice is patulin, a mycotoxin produced by several species of mold. These molds are present in bruised apples and cannot be removed during washing. FDA guidance establishes a maximum level of 50 µg/L in foods. However, in 1993 the FDA found that one in five samples of apple juice contained patulin concentrations above 50 µg/L.

Pasteurization also inactivates polyphenol oxidase (PPO), the enzyme responsible for the browning (oxidation) of apple juice. Clarified apple juice is typically pasteurized at 95 ºC for 10–30 sec or at 85 ºC for 15–120 sec (Lea, 1990).
15.2.2.5 Product quality

The composition of apple phenolics depends largely on variety, maturity, storage, and extraction conditions. Concentrations of phenolics change drastically during processing, mainly by the action of PPO. This enzyme is mostly bound to the cell membrane. When juice is allowed to oxidize with pulp, total polyphenols decrease in the clarified juice due to adsorption of colored compounds onto pulp particles. Total polyphenol content also decreases. In contrast, when clarified juice is allowed to oxidize, discoloration increases until PPO is inactivated by the products of phenolic oxidation. Addition of ascorbic acid or SO₂ to inhibit the enzyme and reduce oxidation products can be done to control discoloration (Lea, 1990).

The overall aroma compound concentration of apples is estimated at around 200 ppm. Early characterization of aroma active compounds identified 56 volatile compounds, out of which only three (1-hexanal, trans-2-hexanal, and 2-methyl butyrate) had “apple-like” characteristics (Flath et al., 1967). Hexanal and trans-2-hexanal are formed after disruption of the cell structure during processing. A more recent study of apples of selected cultivars at selected levels of maturity reported 36 aroma active compounds, of which 24 were common to all the extracts analyzed (Mehinagic et al., 2006). Butyl acetate, 2-methylbutyl acetate, hexyl acetate, and hexyl hexanoate have been associated with the overall aroma of fresh (Young et al., 1996) or stored apples (Lopez et al., 2000; Plotto et al., 1999).

Apple juice quality is assessed by SSC and TA, but in contrast to orange juice, where TA is reported as citric acid (triprotic), for apple juice TA is reported as malic acid (biprotic). Also in contrast to citrus juices, most apple juice is clarified. Therefore, turbidity is assessed. Because pectin contributes to the stability of the cloud, the so-called “alcohol precipitation” method is used to determine residual pectin content. Acidified ethanol is added to the juice after enzyme treatment to precipitate water-soluble pectin. Adequate clarification results in little to no precipitation.

Like any other juice, apple flavor is affected by pasteurization temperature and time. However, thermal processing has a less pronounced effect on the acceptability of apple juice compared to orange. Therefore, shelf-stable apple juice is the most common. Non-thermal processing of apple juice has been widely researched. Higher retention of volatile aroma compounds has been reported for non-thermal technologies (Aguilar-Rosas et al., 2007).

A major concern in the international marketing of juice concentrates is the content of pesticides that are not volatile and therefore appear in concentrations above the limits approved by some countries or are not allowed at all in certain countries.

15.2.2.6 Major processors and markets

The largest exporters of apple juice concentrate are Poland, Austria, Hungary, US, and Ukraine. Poland accounts for 28.1%, Austria for 10.5% and the rest, under 10%. The largest exporters of single-strength apple juice are China, Germany, Italy, Poland, and Austria. China accounts for 51.9%, and all others under 10% of the world exports (FAO, 2010). The largest importers of apple juice concentrate are US, UK, Russian Federation, Japan, and Germany. The US accounts for 36.5% of imports. The largest importers of single-strength apple juice are Germany, Netherlands, France, Austria, and US, with Germany accounting for 33.2% of the imports (FAO, 2010).

15.2.3 Tomato

15.2.3.1 Growing regions, world production, and major producers

Tomatoes are grown worldwide for the fresh market, the processing market, and increasingly the fresh-cut market. The fresh-cut market is usually included in fresh tomato statistics. Tomato (Lycopersicon esculentum) is the second most important vegetable crop in the world, followed by potatoes (FAO, 2010). In 2003, the US production of fresh-market tomatoes was over 1.6 million tonnes, with Florida and California responsible for 43% and 28%, respectively, of that amount (Sargent et al., 2005). In comparison, the 2003 US figure for processing tomato production was 9.8 million tonnes, with that figure rising to 14.0 million tonnes in 2009 (ERS, 2010). California produces about 95% of all US tomatoes used for processing into products such as sauce, paste, canned products, and juice. Worldwide production of tomato totaled 158,368,530 MT in 2009, an increase of 3.7% from the previous year. The top tomato producer in 2009 was China, which accounted for about 25% of the world production, followed by the US, Turkey, India, Egypt, and Italy (NASS, 2010).

15.2.3.2 Harvest and handling for processing

Tomatoes for processing can be mechanically harvested, a process that has been utilized since the mid-1960s and that is widely recognized as one of the reasons for the success of the California processed tomato industry. The tomatoes are transported to the processing plant as
quickly as possible, and unloaded as soon as practical. Fruit quality can deteriorate rapidly even if the trucks are shaded. Tomatoes are off-loaded onto belts or conveyors, or sometimes into water-filled flumes. The major handling step at this part of the process is grading. In the US, voluntary quality standards may be adopted or grading may follow that outlined in the marketing order pertaining to processing tomatoes that are destined for paste and juice (the Processing Tomato Advisory Board). In any grading schedule, the purpose is to establish quality standards for processing tomatoes and to conduct a grading program to assure the orderly marketing of uniform quality processing tomatoes. Tomatoes are graded primarily on the basis of color and defects (worms, weather damage, mechanical harvesting damage, mold, and decay). For the production of juice and paste products, the SSC is important and is considered in the grading process.

15.2.3.3 Process description

Figure 15.9 outlines the major processing steps for processed tomato juice and paste (concentrate). After grading, tomatoes are washed to remove dirt, insects, mold, and other possible contaminants. Proper washing results in products that are of better quality (microbial and hygiene) and can be enhanced by several practices: agitation of the fruit to physically remove the soil, warm water spray or dip (although water is more often used to cool the product), application of a surfactant to help remove soil, and transport through a water flume. The water flume is used to minimize damage to the fruit during handling and also to separate the physical debris that might have been picked up during the mechanical harvesting process. A final rinse is generally accomplished through a spray nozzle system.

15.2.3.3.1 Sorting

Optical color sorting is used to remove green and pink tomatoes from the fruit stream. Color is an important attribute of tomato juice (see discussion below) and while green tomatoes do not adversely affect the color of juice in small numbers, pink tomatoes significantly affect the red color in even small numbers. For juice or paste, tomato size is unimportant. A final sorting may take place where human sorters are utilized. Any unacceptable tomatoes and debris are removed and discarded at this step.

15.2.3.3.2 Break

A relatively unique operation in the production of tomato juice and paste is the so-called break process. Tomatoes can be processed into juice by either a hot break or cold break method, although the hot break is most common for juices that are further processed into concentrate. Briefly, the hot break method involves chopping the tomatoes and heating the resultant mixture to at least $85^\circ C$ to inactivate pectolytic enzymes that would, if not inactivated, result in the loss of desirable high viscosity in the tomato product. As most tomato juice is converted...
into tomato paste, the retention of viscosity is a desirable quality attribute. Most hot break processes are conducted at 92–99°C for fast inactivation of enzymes. The cold break process is favored by tomato juice processors who do not necessarily require a high viscosity product or who might be using or selling the juice as an ingredient in another beverage. In this case, the tomatoes are chopped and mildly heated to temperatures around 60–66°C, the optimum range for enzymatic activity. The resultant tissue breakdown leads to higher yields, as well as slightly lower viscosity of the resulting juice. In cold break PME activity resulted in the fast formation of methanol and increased TA (Anthon & Barrett, 2012).

15.2.3.3 Juice extraction

After the break process (hot or cold), the seeds and skins are removed through a finishing or pulping step that also serves as the juice extraction method. Either paddle or screw-type finishers can be used, although screw finishers generally result in better retention of bioactive compounds such as lycopene and ascorbic acid due to less inherent aeration compared to paddle finishers. Juice is de-aerated to remove oxygen incorporated during extraction that would otherwise rapidly oxidize bioactive components. Oxidation is exacerbated by the high temperatures resulting from hot break. Vacuum de-aeration is the type most commonly employed for the removal of entrained and dissolved oxygen, as with many other juice and beverage products.

15.2.3.3.4 Homogenization

Tomato juice can be homogenized to prevent separation of solids from the serum, and this can also cause a slight increase in viscosity. Homogenization is accomplished by forcing the juice through small orifices at high pressures; instead of the fat globule reduction that occurs in dairy homogenization, a shearing of pulp and solids particles takes place, thus leading to increased stability of the juice. High-shear in-line mixers have replaced some homogenizers in the juice industry because of their lower capital and operation costs.

15.2.3.3.5 Packaging

Prior to filling into a consumer package, salt is usually added as an ingredient, along with ascorbic acid, which is added to achieve 120% of the Referenced Daily Intake (CFR 21 104.20) in a 240 mL (8 oz) serving. The exact level of these ingredients depends on the consumer market for which the product is intended. As neither ingredient contributes to the soluble solids of the juice, the juice can still be labeled as 100% juice, which is defined as all of the soluble solids (mostly sugars) being derived from the fruit/vegetable and the product meets the minimum SSC level as defined by the FDA. Tomato juice is commonly packaged in cans that are hot filled and heat treated, bottles that are hot filled, or aseptically packaged in barrier-layer packages; these products are all considered shelf stable with a 1–2-year shelf life. Alternatively, the juice can be pasteurized and filled into plastic (usually PET) bottles and sold as a refrigerated product with a somewhat more limited shelf life of 1–2 months.

15.2.3.3.6 Concentration

If the final product is not juice, the juice is next concentrated to paste. Concentration occurs in forced circulation, multiple-effect, vacuum evaporators. Typically, three- or four-effect evaporators are used, and most modern equipment now uses four effects. The temperature is raised as the juice goes to each successive effect. A typical range is 48–82°C. Vapor is collected from later effects and used to heat the product in previous effects, thus conserving energy. The reduced pressure (~350–700 mmHg) lowers the temperature, minimizing color and flavor loss. The paste is concentrated to a final solids content of at least 24% natural tomato soluble solids (NTSS) to meet the USDA definition of paste.

Commercial paste is available in a range of solids contents, finishes, and Bostwick consistencies. The larger the screen size used for extraction, the coarser the particles and the larger the finish. Bostwick measurements may range from 2.5 to 8 cm (tested at 12% NTSS). The paste is heated in a tube-in-tube or scraped surface heat exchanger, held for a few minutes to pasteurize the product, then cooled and filled into sterile containers, in an aseptic filler. A typical process might heat to 109°C, then hold for 2.25 min or heat to 96°C and hold for 3 min. Aseptically processed products must be cooled before filling, both to maintain high quality and because many aseptic packages will not withstand temperatures above 38°C. An aseptic bag-in-drum or bag-in-crate filler is used to fill the paste into bags previously steam sterilized. Paste is typically sold in 55 gallon drums or 300 gallon bag-in-box containers.
15.2.3.4 Relevant processing conditions

Tomato juice quality is highly dependent on utilizing the proper time-temperature regimes throughout the entire production process. These processes affect the microbial stability of the product, as well as the enzymes inherent in the tomato fruit. These processes in turn have a profound effect on product quality, including nutritional and sensory quality.

15.2.3.4.1 Microbial inactivation

Canned tomato juice is a traditional product, and canning protocols have been well known since the 1920s. Individual tomatoes range in pH from 4.05 to 4.65, although in general, the pH of tomato juice without the addition of some sort of acid is in the range of 4.1–4.35, which is quite close to that of a non-acid food product. In some cases small amounts of citric or ascorbic acid are added to minimize the risk of spore-forming microorganisms causing quality or safety issues with juice. A typical heating regime for a non-acidified tomato juice is heating the juice to 121 °C for 45 sec, cooling to 93 °C in order to fill the package, then sealing the package and agitating, maintaining that temperature for 3 min, in order to achieve overall commercial sterility. This process is designed to destroy the vegetative cells and the spores of *Bacillus* spp., which are the most common spoilage organisms of tomato juice. Specifically, *B. coagulans* is responsible for the common type of tomato and tomato juice spoilage termed “flatsour” which is not evident by package swelling or obvious spoilage, but has an uncharacteristic acidity due to the production of lactic acid.

Tomato juice packaged in plastic bottles and sold in a refrigerated case undergoes a less rigorous prepackaging pasteurization regime, as the enzymatic treatment has already occurred during the break process and the product has a limited shelf life. Spore-forming microorganisms are generally not an issue with refrigerated products over their limited shelf life as long as proper refrigeration is maintained.

15.2.3.4.2 Enzyme inactivation

Pectolytic enzymes are the focus of the previously discussed break process. The two major enzymes are polygalacturonase (PG) and pectinmethylesterase (PME). Enzyme activity of PG and PME is slowed or stopped through the high temperatures that occur in the hot break process as described above, and enhanced under the cold break process as the pectolytic enzyme activity is at its maximum at the cold break temperatures of 60–66 °C. Although both processes have been utilized for several decades, researchers continue to elucidate the exact mechanism of pectin breakdown and subsequent physical parameters as a result of these processes (Chong et al., 2009; Lin et al., 2005).

15.2.3.5 Product quality

Tomato juice quality can be assessed through voluntary grading programs, for example, US Grade A Fancy, but this discussion will focus on the accepted technical measures of tomato juice quality. The soluble solid content of tomato juice, if reconstituted, must reach the minimum of 5.0 °Bx upon reconstitution and packaging of the juice (CFR 21-101.30). Additionally color, viscosity, flavor, and defect level are factors that are included in the quality assessment.

The nutritional quality of tomato juice is thought to be due to high levels of the antioxidant lycopene, which is also responsible in large part for the red color of the tomato juice. Processing and storage techniques have developed with the purpose of maintaining as high levels of lycopene as possible. The ascorbic acid content, whether endogenous or added, also contributes to antioxidant activity of tomato juice (Jacob et al., 2008), which enjoys a relatively healthy image, especially in low-sodium forms.

15.2.3.6 Major processors, markets, and sustainability

A global trade organization for tomato processing supports the industry worldwide (World Processing Tomato Council; www.wptc.to/) with the California processing industry the major representative in the US. Major tomato processors worldwide include Hunts and Contadina, and increasing numbers of processors in China.

Waste water disposal is a major issue in the tomato processing industry, due to both the amounts of water used in fluming operations and the strict environmental laws in the major US tomato processing area.
15.2.4 Carrot

15.2.4.1 Growing regions, world production, and major producers

Carrots, a member of the parsley family (Umbelliferae), are thought to have originated in central or western Asia but are grown worldwide. Carrot cultivation in the US was first practiced several centuries ago by early settlers in the Virginia region (AGMRC, 2011); by 2004 the US was the third largest carrot-producing country. Russia produced slightly more carrots but the production from both countries was dwarfed by that of China during the 2004–2009 period. Total US carrot production for the fresh and processing markets was valued at more than $627 million in 2010 (NASS, 2010). The US carrot market is overwhelmingly fresh, representing 95% of the value of the crop in 2010. California, Michigan, and Texas were the top fresh carrot-producing states, with California representing the majority of fresh market production (84%). Processed carrot products, including canned, frozen, dehydrated and juiced, represented just 5% of the total value of the carrot market in 2010; Washington, Wisconsin, Minnesota, and California were the leading producers of carrots for the processed market (AGMRC, 2011). Carrot juice has traditionally been a home-processed product and is sold in many food service outlets and juice bars, particularly those targeting the “health and wellness” consumer (Sloan, 2012). While there are several large, global carrot juice producers and packagers, carrot juice is still a relatively small portion of the overall processed carrot category; except for proprietary sales figures there is little data available for US or global processed carrot juice consumption.

15.2.4.2 Harvest and handling for processing

Carrot production in the US is highly mechanized and carrots grown for processing are usually selected for yield, processing utility, and maturity at a consistent time. The Chantenay variety is most often used for processing, due to its larger relative size and high soluble solids. Some fresh varieties are processed as culls from fresh or fresh-cut operations. Carrots destined for both fresh and processed markets are mechanically harvested (AGMRC, 2011), usually from August to late fall in the western US.

15.2.4.3 Process description

Carrots are delivered in bulk to the processing facilities, either directly from field harvest or as culls from fresh pack or fresh-cut operations. Figure 15.10 represents a simplified summary of typical carrot juice processing operations. Carrots, topped by the removal of excess leafy greens, are rinsed to remove excess dirt, washed with cold water and sent to the comminuter unpeeled. The carrots are run through a size-reduction device, often a hammer mill, to achieve a finely ground start. The mash may be

![Figure 15.10 Flow diagram of carrot juice production.](image-url)
heat-treated to inactivate native enzymes (see Enzyme Inactivation section) or treated with enzymes to enhance yield, then the carrots are pressed to extract the juice from the mash. The type of press most often used is a continuous belt press, but a bladder press is occasionally used in small batch operations. After pressing, the juice may undergo centrifugation to remove small particles of pulp, or the juice may be decanted in a vessel to achieve removal of the larger particles. Carrot juice can also be concentrated to 42–50ºBx, sent to a pasteurizer or sterilization unit for bulk storage or filling into consumer packages, or canned and retorted under sufficient conditions to assure shelf stability.

15.2.4 Relevant processing conditions

15.2.4.1 Microbial inactivation
Carrot juice is classified as a low-acid product and has traditionally been processed and filled into cans and bottles in a manner that will prevent the growth of *Clostridium botulinum*, a spore-forming bacterium that can produce a highly potent toxin at pH greater than 4.6, anaerobic environment, and non-refrigerated temperatures. Specific processes have been developed to destroy the spores of this organism. Chilled carrot juice is not required to undergo this rigorous thermal process, but due to a recent outbreak of temperature-abused chilled carrot juice, there are still safety issues associated with the refrigerated product. Processors use a variety of hurdle processes such as acidification, pasteurization, and carrot surface treatment to ensure the safety of this product and warn consumers with adequate labeling.

15.2.4.2 Enzyme inactivation
Carrots processed as frozen, canned or dehydrated products are blanched at approximately 90 ºC for 3–5 min to inactivate enzymes that might otherwise result in degradation of the preserved product. The enzyme of most interest in carrot juice is PME which, as in the case of orange juice, causes precipitation of the cloud (Reiter et al., 2003). This is in contrast to tomato juice, where the pectolytic enzyme inactivation is primarily used to manipulate juice viscosity.

15.2.4.5 Product quality
The standard SSC of carrot juice, as designated by the FDA, is 8ºBx. This measure of soluble solids, comprising almost all sugars in the case of carrot juice, represents the minimum level to which a carrot juice product could be diluted with water. Carrot juice processed as NFC may have slightly higher or lower SSC, depending on the maturity and type of carrot. There are no federal grade standards for carrot juice due to its relatively small market, but consumer testing has determined that color, fresh carrot taste, sweetness, and low bitterness are important attributes in producing a desirable product.

15.2.4.6 Major processors, markets, and sustainability
Two major carrot operations in California dominate the production of carrot juice: Bolthouse Farms and Grimmway Farms. As both plants operate in California, there are substantial environmental issues that impact the production of carrot juice. These include the ever-present tension of water use for agriculture in areas of high urban pressures, as well as the need to thoroughly treat and minimize any waste water produced in the plant.

Organic carrot production has increased in recent years, and organic carrot juice can be found in some smaller outlets. The sustainability of organic food production and products is perceived by some consumers as being superior to that of conventional products.

15.3 Nectars

As described in the Classification and Regulations section, nectars are prepared by addition of water, sugars, and other ingredients to a fruit paste, concentrate, or purée. Hence, essentially, nectars can be made from any fruit, including the ones that are typically sold as juices. Even though in some countries, nectars produced by diluting juices are popular because of their lower cost and local preference for such beverages, most of the nectars sold as such in the market come from fruit from which a juice could not be produced because of the high viscosity and low SSC relative to single-strength juices. Some of the most common nectars found in the market are apricot, guava, mango, peach, pineapple, and strawberry. Mango, peach, and other stone fruit are processed in a very similar way. Therefore, in this section we only describe mango processing.
15.3.1 Mango

15.3.1.1 Growing regions, world production, and major producers

Mango (Mangifera indica) is a tropical climacteric fruit. It can grow at altitudes from sea level to 1200 m and in frost-free subtropical regions. India is the largest producer of mangoes with 13.5 million MT, followed by China, Thailand, Indonesia, Pakistan, and Mexico, all producing more than 1.5 million MT. The world total production was almost 33 million MT in 2009. There are hundreds of varieties. The most important varieties in India include Alphonso Toatpuri, Kesar, and in Mexico and Brazil, Tommy Atkins and Palmer. In 2009, world exports of mango juice were 90,582 MT, with a value of $49.0 million (FAO, 2010).

15.3.1.2 Harvest and handling for processing

Mangoes are harvested during the summer, unripe but mature, 75–135 days after blooming. In regions closer to the equator, harvesting periods are more extended. Mangoes are typically harvested by hand, avoiding caustic sap getting in contact with the fruit peel, as it can produce undesirable dark spots and localized softening. This is more of a problem for fruit directed to the fresh market than for processing. Fruit is then ripened in controlled temperature rooms. Ripening can be achieved in two days (Wu et al., 1993).

15.3.1.3 Process description

Mango purée is best produced from varieties that are not fibrous and produce a smooth purée. Because of the large diversity of cultivars with different quality attributes including color and flavor, mango purées are often blended. Depending on the cultivar, peel represents between 6.5% and 24.4% of the fresh fruit weight and the flesh accounts for 32–85%. Detailed information for each cultivar was reported by Wu et al. (1993). Often, purées are produced by processors different from those who produce nectars. Nectars are then produced by major brands or co-packed by large juice processing plants. A flow process diagram of mango nectar production is shown in Figure 15.11.

15.3.1.3.1 Washing and sorting

Mangoes are dumped into a conveyor, where they are rinsed with a manifold of water spray nozzles and culls are removed by hand. The fruit is then brush-washed and rinsed on the conveyor.

Figure 15.11 Flow diagram of mango nectar production.
15.3.1.3.2 Peeling

Varieties with thin skin and low content of polyphenols may be processed without peeling but other varieties require peeling to avoid introduction of off-flavors. Where labor costs allow, mangoes are peeled raw by hand using knives. Mangoes can be scalded (steamed) for 2–3 min, cooled down in water, and the peel is removed by hand. This scalding step not only facilitates peel detachment but achieves microbial reduction. Lye peeling is done for thin-skinned mangoes. The fruit is scored (i.e. an incision is made) with stainless steel brushes and immersed in hot sodium hydroxide solution (~20%) with a surfactant. Then, the peel is removed by water washing and abrasion on a rotary rod.

15.3.1.3.3 Pulping

Mangoes are pulped in a paddle pulper or destoner where the seeds are separated. Disintegrated flesh is separated from peel residues and fibrous material and other defects in centrifugal separators or finishers. This process is also called refining. Because of differences in cultivars and levels of maturity, mango pulp pH varies from batch to batch and needs to be lowered to ensure microbial stability. To minimize browning and other oxidative reactions, mango puree is often de-aerated prior to pasteurization.

Some processes include enzymatic liquefaction to reduce viscosity and increase yield but require additional thermal inactivation of the added enzymes.

15.3.1.4 Relevant processing conditions

15.3.1.4.1 Microbial inactivation

Pulp is then pasteurized at 90 ºC for 1 min and stored frozen. Because of its high viscosity, pasteurization is typically done in scraped surface heat exchangers. Aseptic pulp systems are also available. During the production of nectar, after water, sugar and ingredient addition, nectar is again pasteurized at 95 ºC for 1 min and packaged aseptically in plastic-lined carton containers for retail sale. Alternatively, mango nectar can be heated to 80 ºC, filled in cans held at the same temperature for 10 min, and then cooled down.

15.3.1.4.2 Enzyme inactivation

Polyphenol oxidase is the most relevant enzyme affecting the quality of mango puree and nectar, as it causes product browning. Peroxidase, a more thermally stable enzyme, may have some residual activity without impacting quality.

15.3.1.5 Product quality

The Codex general standard for fruit juices and nectars stipulates that mango nectars should have at least 25% v/v content of mango pulp (CODEX STAN 247-2005). Soluble solid content is between 12 and 18ºBx, pH around 3.4, and TA between 0.2% and 0.3% as citric acid. Color and aroma are the most relevant fruit-derived quality attributes. Of processed mangoes, Alphonso has the richest aroma profile; however, other cultivars such as Tommy Atkins and Totapuri are commonly used. The effects of pH, high hydrostatic processing and anti-browning agents as alternative non-thermal processes have been studied (Guerrero-Beltran et al., 2005, 2006).

15.3.1.6 Major processors, markets, and sustainability

According to the Food and Agriculture Organization (FAO, 2010), in 2009, the largest exporters of mango purée or juice were Egypt, China, the Philippines, Jordan and Senegal, and the largest importers are China, Jordan, Libya, Maldives, and Senegal. However, the largest producers of mango purée are India, Mexico, Colombia, Egypt, and Thailand. About 30% of mango fruit is peel or seed and in most cases it is waste. There have been some studies to recover lipids and antioxidants from seed kernels (Puravankara, 2000), or to make flour from pulp and peel (Noor Aziah et al., 2012). Mangoes grow in the wild in many poor tropical countries and opportunities exist to develop local and export markets in countries like Mali or Haiti, where producers and processing plants can hire many people for harvesting and sorting and help boost such economies.

15.4 Clean-in-place

Equipment sanitation is a critical part of the economical sustainability of any food processing operation. Failure to adequately sanitize a processing line may result in product contamination, costly product recalls, and consumers getting sick. Also, a large portion of waste water comes from equipment sanitation. Prior to clean-in-place (CIP), processing plants were periodically disassembled and each piece of pipe and equipment was sanitized by hand. Pipes
were immersed in cleaning solutions and sanitized with chlorine solutions at concentrations that occasionally led to stainless steel corrosion. CIP became possible as a result of process automation and control and the design of equipment with washing ports and configurations accessible to cleaning solutions and rinsing.

Installation of a CIP requires the additional capital investment of CIP tanks, heat exchanger, special valves (such as double-seat and double butterfly), instrumentation, and programmable logic controllers (PLCs). A CIP also almost doubles the length of pipe required to supply and return the CIP solutions. However, the payback is twofold: significantly lower labor costs and enhanced product safety and quality. CIP solutions are prepared by pumping solution concentrates (caustic or sanitizer) to CIP tanks. After the product has been processed, all pieces of equipment, tanks, and pipes with which the product was in contact must be sanitized.

In a typical CIP system (Figure 15.12), the first step is to rinse at about 50 ºC. A plate heat exchanger is typically used to heat in a single pass the first rinse solution, which is fed from the main treated water supply. Then, a hot (~85 ºC) caustic solution, typically 2% sodium hydroxide, is used to dissolve oily materials. Solubility of food residues increases with temperature. Heat also contributes largely to microbial kill. The caustic solution is heated to the set point by pumping it through the heat exchanger and circulating to the caustic solution tank until the temperature at the exit of the heat exchanger reaches the desired level. The set point is often determined by a threshold temperature at the return of the CIP.

The following steps are a temperate rinse, a cold rinse, and then a cold sanitation using peracetic acid and other sanitizers. Sanitation is often done cold, and the concentration is low, otherwise polymer (Buna or EPDM) gaskets used in pipe unions and equipment seals can be chemically degraded. However, today some processors prefer hot sanitizers and use Teflon or Viton gaskets. In this stage, microbial kill is chemically driven. Finally, a last rinse, typically used to remove sanitizer residues, is done.

Critical to the effectiveness of any CIP is adequate mechanical shear between the rinses and CIP solutions and the wall of pipes and other pieces of equipment. Mean flow velocities of 1.5–2.1 m/sec are recommended in pipes. Impingement or shear stress in tank surfaces is not uniform and largely depends on the size of the tank, the flow rate of solutions, and the design and location of the spray ball or nozzles used. A very important factor is the duration of the CIP. In theory, there are an infinite number of combinations of CIP solution formulations, temperatures, and flow rate that can achieve adequate sanitation. Heuristic rules are used as starting points, and each processor adjusts them to their specific need. One must bear in mind that even identical systems in which the same product is processed may need different CIP conditions. For example, a juice processing plant

![Figure 15.12 Schematic representation of a two-tank clean-in-place (CIP) system.](image-url)
located at a high elevation cannot use a temperature as high as one at sea level without producing a steam bath. Also, the microbial populations in a particular location may be different, i.e. be more or less tolerant to heat or sanitizer, from another.

Water from the first rinse contains large loads of dissolved and suspended solids. Small juice processors have to drain it, pay fees, and in some cases fines to the municipality to treat the effluent. Larger processing facilities send the waste water to their own water treatment plant to reduce the organic matter content to acceptable levels so that it can then be discarded to the municipality or used for irrigation if located near agricultural land. In small to medium size juice processing plants, a two-tank CIP system like the one shown in Figure 15.12 is common. However, large processors use a third tank in which water from the last rinse is recovered and used for the first rinse. This makes the operation more economically and environmentally sustainable. Other processors use an additional buffer tank with water for the first rinse and even a fifth tank with hot water.

Juices and juice concentrates are often transported from processors to packers in tanker trucks. Proper sanitation is crucial. Tankers with only one port for CIP nozzles may not be properly sanitized, especially when the port is not located near the middle of the tanker. Validation of tanker sanitation is, in many cases, still needed.

In summary, effective CIP requires considering the flow rate, temperature, chemical concentration, and time of each step. To ensure the efficacy of routine CIP, processors use rapid methods based on swabs of selected pieces of equipment and determine by bioluminescence the amount of residual adenosine triphosphate (ATP). Although ATP determinations are non-specific, this type of test has proven very valuable and affordable. Finally, as alternatives to conventional caustic and acid sanitizers, the use of ozone or electrochemically activated water (EAW) has been proposed. Despite its outstanding oxidizing power, ozone does not have a surfactant effect, so for most juices, a caustic wash is required. Also, all gaskets must be EPDM, Viton or Teflon. With regard to EAW systems, more research needs to be done to assess their efficacy and their impact on processing equipment.

15.5 Conclusion

In summary, although processed fruit and vegetable juices have been on the market for decades, new technologies continue to be developed to improve quality retention, nutrition value, and shelf life. Thermal processes that ensure product safety and acceptable product shelf life will continue to be predominant. However, as the cost of non-thermal technologies decreases, a greater number of products are expected to become available, still at a premium price. Consumers, processors, and governments have become increasingly aware of the impact of industrial operations in the environment, especially as population in urban areas continues to grow. Technologies that minimize energy consumption (e.g. carbon footprint) and maximize efficient use of water are becoming increasingly relevant to ensure the sustainability of the fruit beverage industry.

References


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Further reading


