Fruit Processing

Ömer Utku Çopur and Canan Ece Tamer

1 Introduction

The quality of processed fruit products depends on their quality at the start of processing; therefore, it is essential to understand how maturity at harvest, harvesting methods, and postharvest handling procedures influence quality and its maintenance in fresh fruits between harvest and process initiation (Kader and Barrett 2005). The specific qualities required in fruits and vegetables will depend on their end-use and the selection of appropriate cultivars for particular products is of paramount importance (Aked 2002). Quality of fresh produce includes appearance (size, shape, color, gloss, and freedom from defects and decay), texture (firmness, crispness, juiciness and toughness, depending on the commodity), flavor [sweetness, sourness (acidity), astringency, aroma, and off-flavors], and nutritive value. Nutritional quality is determined by a fruit's content of vitamins, minerals, dietary fiber, carbohydrates, proteins, and antioxidant phytochemicals (carotenoids, flavonoids, and other phenolic compounds) (Kader 2001; Kader and Barrett 2005).

Despite the beneficial health effects of fresh produce, there is a growing awareness concerning its microbial and chemical food safety (Lynch et al. 2009; Strawn et al. 2011). There was in general an agreement on the main priorities in food safety of fresh produce. Bacterial pathogens were overall considered to be the most important food safety issue for fresh produce, followed by foodborne viruses, pesticide residues, and mycotoxins. Other food safety issues such as antimicrobial resistance, wax coatings, nanomaterials, and genetically modified organisms are increasingly becoming a concern for the fresh produce supply chain

Ö.U. Çopur (✉) • C.E. Tamer
Faculty of Agriculture, Department of Food Engineering, Uludag University, Bursa, Turkey
e-mail: ucopur@uludag.edu.tr

A. Malik et al. (eds.), *Food Processing: Strategies for Quality Assessment*,
Food Engineering Series, DOI 10.1007/978-1-4939-1378-7_2

(Tait and Bruce 2001; Domingo and Gine Bordonaba 2011; Magnuson et al. 2011). Hence, assuring the safety of fresh produce and alertness to maintain consumer trust in fresh produce as a healthy food is of primary importance for stakeholders. This is a challenging task in an increasingly globalized and more complex fresh produce food supply chain. It implies a shared responsibility of the stakeholders within the farm-to-fork continuum (producers, processors, trading companies, retailers, and consumers) and those closely involved in supporting food safety in the supply chain (competent authorities, industry associations, food scientists). Alert systems such as the European Commission's Rapid Alert System for Food and Feed (RASFF) were considered as the most important source of information of food safety issues, followed by reports of international organizations (e.g., WHO, EFSA), legislative documents (e.g., EU legislation), national reports (e.g., on monitoring hazards, foodborne outbreaks), and exchange of information between people. Concerning the control measures, the application of good agricultural practices (GAP) was identified to be the most important control measure to assure the safety of fresh produce, followed by the application of good hygienic practices (GHP) and the certification of food safety management systems (FSMS) (Van Boxstael et al. 2013). Today's management of food safety is to a great extent based on the application of the HACCP system. Originally, the system was introduced to ensure the microbiological safety of food products. Later on, its use was extended to all types of foodborne hazards, including chemical hazards (Motarjemi et al. 2009). As the primary source of raw ingredients for food production, the agricultural sector is a fundamental component of the most food product and supply chains. Consequently, the development of effective HACCP procedures for this sector is essential to the overall success of HACCP (Ropkins et al. 2003). Current attention in chemical HACCP is mainly focused on residual chemicals from the agricultural sector (e.g., pesticides, growth hormones, fumigants, and some natural toxins) (Ropkins and Beck 2003).

Increasing international trade and globalization were overall expected to have a large impact on food safety in fresh produce. Other contextual factors perceived to be important were the food safety policies by governments and the (lack of) food safety knowledge by consumers and other stakeholders of the fresh produce supply chain (Van Boxstael et al. 2013).

Food processing operations have a major influence on the stability of phytochemicals and often damage antioxidants in fruit and vegetables and their products. Domestic, industrial, thermal, and nonthermal processing are widely reported to degrade the level of phytochemicals in processed food products. In order to retain the nutraceutical and pharmacological properties of phytochemicals in processed fruit and vegetable products, the food processor must optimize relevant processing steps in order to restrict the loss of phytochemicals (Tiwari and Cummins 2013). In this chapter, quality criteria in freshly harvested produce, the principal causes of quality deterioration and maintaining quality of fruit products, the impact of thermal and nonthermal processing on nutrients and antioxidants of fruit products are briefly discussed.

2 Principal Causes of Quality Deterioration

Exposure of a commodity to temperature, relative humidity, and/or concentrations of oxygen, carbon dioxide, and ethylene outside its optimum ranges will accelerate loss of all quality attributes. The loss of flavor and nutritional quality of fresh intact or cut fruits and vegetables occurs at a faster rate than the loss of textural and appearance quality (Kader 2001). Many factors can lead to loss of quality in fresh produce, hence the common description of these products as "perishable." Some of these factors are part of the life cycle of living produce, that is, over-ripening of fruits or sprouting in root and bulb crops. Others are a consequence of the act of harvesting. Once severed from the mother plant, the plant organ is deprived of its source of water, nutrients, and antisenescent hormones. As a consequence normal factors such as transpiration and respiration lead ultimately to water loss and senescence of the product. The growth of pathogens or physical damage will cause direct loss of product quality through their visual impact but both also stimulate senescence. Furthermore, the storage environment (temperature, relative humidity, air movement, atmospheric composition, ethylene) will play a highly significant role in determining the speed of all quality changes (Aked 2002).

Fruits and vegetables are naturally contaminated with microorganisms, and many of these microorganisms possess pectin-degrading enzymes, enabling them to produce colonization by using fruit nutrients. Moreover, tissue damage originated by cutting or wounding leads to cell damage, releasing nutrients, and favoring growth of most types of microorganisms. They may also cause spoilage and affect the economic value of produce, not only by decreasing the organoleptic and nutritional quality and shelf-life of produce but also by causing foodborne disease. Therefore, it is important to prevent contamination and growth of microorganisms, in order to reduce degradation of nutrients and maintain fruit safety and sensory attributes. Some of these problems can be solved by improving preharvesting practices, and others need to be addressed through appropriate postharvest handling and processing (Ruiz-Cruz and Arvizu-Medrano 2010).

3 Storage and Packaging Techniques for Maintaining Quality of Fruits

Maintaining quality requires action to be taken to limit factors causing deterioration in fresh fruits (Aked 2002). Fruit storage technology deals essentially with the inhibition of natural, physical, pest-induced, and pathogen-induced decay and damage without going to extremes such as drying or freezing. The object is to maintain fresh quality as long as possible or as long as necessary, depending on market conditions. The two broad categories of obstacles in achieving these objectives are: "the biochemical and physiological activities that proceed within the fruit itself after harvest" and "the introduction and proliferation of microbial pathogens and insects in the storage environment" (Raghavan et al. 2005).

To prolong the storage life of fresh fruits and vegetables, controlled atmosphere (CA) storage is frequently used. The basic CA effect on biochemical reactions can also be used to extend the shelf life of processed and ready-to-use fruit products. These products are often peeled and sliced and they are preferred as fruit dishes by consumers. The technique that provides CA condition for this ready-to-use fruit dishes is usually modified atmosphere packaging (MAP) (Balla and Farkas 2006). MAP involves the modification of the internal atmosphere composition of a package by reducing the amount of oxygen (O_2) and replacing it by carbon dioxide (CO_2) and/or nitrogen (N_2). This process aimed to extend the postharvest life of whole and fresh-cut commodities by reducing their respiration rate and the production of ethylene, minimizing metabolic activity, delaying enzymatic browning, and retaining visual appearance. The gas re-balancing can be achieved either using active or passive techniques inside a package made of various types and/or combinations of films (Saxena et al. 2008; Cui et al. 2009; Ramos et al. 2013). Several studies have reported that modified/controlled atmosphere packaging delayed senescence and microbial growth in fruits and vegetables. On the other hand, it has been observed that the antioxidant content and bioactivity could vary depending on the kind of treated fruit and treatment (Ayala-Zavala et al. 2005, 2007; González-Aguilar et al. 2010).

4 Impact of Processing on Nutrients and Antioxidants of Fruits

Intact fruits and vegetables obviously are prone to deleterious changes induced by respiratory, metabolic, and enzymatic activities, as well as by transpiration, pest and microbial spoilage, and temperature-induced injury. Most such changes may impact adversely on the antioxidant status of these products (Lindley 1998).

In fruits and vegetables, phytochemicals can be bound in the plant cell membranes or exist as free compounds. Food processing such as heating or freezing can disrupt the cell membrane leading to the release of membrane-bound phytochemicals, which implies higher bioaccessibility (Lemmens et al. 2009). Moreover, the amount of phytochemicals retained in fruits and vegetables depends on their stability during food preparation and processing before consumption, which is mostly related to their sensitivity toward oxidation and the environmental conditions (Leong and Oey 2012).

Food processing operations have a major influence on the stability of phytochemicals and often damage antioxidants in fruit and vegetables and their products. Conventional thermal: (blanching, pasteurization, frying, steaming, baking, stewing, roasting), nonthermal (high pressure processing, pulsed electric field, ultrasound, ultraviolet), domestic (washing, peeling, cutting), and industrial (canning, drying, extraction, concentrating by evaporation, extrusion) processing are widely reported to degrade the level of phytochemicals in processed food products (Tiwari and Cummins 2013).

Heat treatment may lead to a decrease in essential nutrients and consequently reduces the nutritional value of some foods. In this context, some water-soluble vitamins (vitamins C, B1, B2, B6, and folic acid) are heat sensitive, while lipid soluble vitamins are relatively stable to heat. The Maillard reaction itself may also lead to the loss of vitamins and proteins due to the transformations involved in the reaction. However, a first and often very important loss of vitamins and minerals already occurs prior to any heat treatment, when the raw materials are physically prepared. This may occur by the practice of peeling fruits or vegetables. The amount of minerals in foods is not much affected by processing, except when this includes discarding certain constituents. Unit operations such as cooking, drying, extrusion, and so on have little effect on the bioavailability of minerals (Burri et al. 2009).

Food processing and subsequent storage conditions may have a positive or negative influence on the stability of phytochemicals (Aaby et al. 2007; Volden et al. 2009; Rawson et al. 2010; Tiwari and Cummins 2013). Maceration, heating, and various separation steps can result in oxidation, thermal degradation, leaching, and other events that lead to lower levels of antioxidants in processed food compared with fresh. This is particularly true in the case of vitamin C and phenolic antioxidants. However, in the case of carotenoids, processing can lead to a dissociation of antioxidants from plant matrix components, an increase in carotenoid antioxidants, and improved digestive absorption (Kalt 2005).

During the processing of fruits and vegetables, several types of oxidative reactions may occur in which electrons are removed from atoms/molecules leading to the formation of an oxidized form. These reactions cause browning, loss or changes of flavor or odor, changes in texture, and loss of nutritional value from destruction of vitamins and essential fatty acids (Dziezak 1986). The oxygen also can play a major role in the flavonoids degradation during the different steps of processing and storage. The presence of oxygen can accelerate the degradation either through a direct oxidative mechanism and/or through the action of oxidizing enzymes as polyphenoloxidase (PPO). For this reason, the degradation of flavonoids is a combination of several mechanisms depending on the operating conditions and the food matrix (Ioannou et al. 2012).

While most vegetables are cooked at domestic level prior to consumption, fruits are consumed raw or undergo minimal processing which has been defined as a combination of procedures, such as washing, sorting, trimming, peeling, and slicing or chopping, that do not affect the fresh-like quality of the food (Odriozola-Serrano et al. 2008a; Tiwari and Cummins 2013). "Fresh-cut" is defined as any fruit or vegetable or combination that has been trimmed, peeled, washed, and cut into 100 % useable product that is then bagged or prepackaged and remains in a fresh state (Lamikanra 2002). Fresh-cut fruits and vegetables are highly perishable products because of their intrinsic characteristics and the minimal processing (Ayala-Zavala et al. 2008a). Microbial growth, decay of sensory attributes, and loss of nutrients are among the major causes of compromised safety and quality of fresh-cut produce. These problems are caused by the steps involved in the minimal processing, such as peeling and cutting, which promote an increment in the metabolic rate, enzymatic reactions, and released juice (Ayala-Zavala et al. 2008b).

Peeling, trimming, depitting, and/or leaf selection may cause a partial or total decrease in flavonol levels (Amarowicz et al. 2009).

Vinha et al. (2013) demonstrated that the removal of the skin of tomato caused a loss of 80 % of lycopene, 63 % of phenolic compound, 57 % of β-carotene, and 26 % of ascorbic acid. Removing the seeds caused 63 % loss of total phenolics. Size reduction (dicing and slicing) results in increasing losses through increasing the surface to volume ratio (Ramaswamy and Chen 2002). Robles-Sánchez et al. (2009) evaluated the losses of bioactive compounds that occur after cutting and cold storage and their contribution to the total antioxidant capacity of fresh-cut mangoes. No significant losses of total phenols were found at the end of storage. Mangoes treated with the antioxidants maintained better quality and higher antioxidant potential compared with controls. Although minimally processing of fruit accelerates ripening of fresh-cut tissues, which could promote an increase in β-carotene content, it is possible that low storage temperature used for mangoes retarded its biosynthesis and accumulation. Plaza et al. (2011) investigated the effect of minimal processing on the health-related characteristics of orange. Carotenoids were retained in minimally processed oranges during refrigerated storage. The flavanone content showed a significant increase throughout refrigerated storage as response to cold stress. Although some vitamin C losses were observed, the antioxidant activity remained stable. Overall, the microbiological quality and potentially health-promoting attributes of minimally processed oranges were preserved during 12 days of storage at 4 °C.

4.1 Thermal Processes

Heating results in enzyme inactivation, texture changes of fruits and vegetables, and unavoidable leaching of water-soluble compounds which could alter the entire phytochemical profile and content of fruit and vegetables. Phytochemicals do not exist as an individual compound; they are mostly bound to other compounds or to cell structures. Due to heat, the disruption of cell membranes occurred. Once the cell is damaged due to heat, this creates an opportunity for the bound phytochemical compounds to be released into the medium, hence they are readily extracted. In fact, heating has been reported to increase the chemical extractability of phytochemical compounds, because of the release of phytochemicals from chromotoplasts leading to an increment of concentration. Heating also encourages the diffusion of cellular fluids, containing phytochemicals, from the plant cell to the water medium (Howard et al. 1999; Leong and Oey 2012).

Jiratanan and Liu (2004) concluded that depending on the particular produce and processing parameters and methods, thermal processing may enhance, reduce, or cause no change in total antioxidant activity from that of fresh produce.

High-temperature processing may lead to thermal destruction of antioxidants. Due to this, long cooking times and sterilization are considered antioxidant-destructive (Grajek and Olejnik 2010). Changes connected to mild hydrothermal processing (<100 °C) are usually advantageous. Due to heating, oxygen is

removed from solutions, oxidoreductases are denaturated, and heteroglycosides are hydrolyzed to aglycones. In other respects, increased temperature may lead to higher losses because a portion of water-soluble antioxidants are extracted. Losses in water-soluble vitamins are a good indicator of the antioxidant potential decrease of a given food product. Blanching, where solid material is in direct contact with steam or hot water, effectively inactivates oxidative enzymes and due to that loss of antioxidants. For example, enzymatic oxidation of vitamin C can be eliminated due to the inactivation of ascorbic acid oxidase. If the process is performed at too low temperature, though, it may be ineffective and lead to polyphenol oxidation by PPO. During treatment, a portion of antioxidants leach into the water, which decreases the antioxidant potential of plant materials (Lin and Chang 2005; Amin et al. 2006; Wachtel-Galor et al. 2008; Leong and Oey 2012).

Rickman et al. (2007a, b) reported that, depending on the commodity, freezing and canning processes may preserve nutrient value. The initial thermal treatment of processed products can cause loss of water-soluble and oxygen-labile nutrients such as vitamin C and the B vitamins. However, these nutrients are relatively stable during subsequent canned storage owing to the lack of oxygen. Frozen products lose fewer nutrients initially because of the short heating time in blanching, but they lose more nutrients during storage due to oxidation. Phenolic compounds are also water soluble and oxygen labile, but changes during processing, storage, and cooking appear to be highly variable by commodity. The higher levels of carotenoids typically found in canned as compared to fresh products may be attributed to reporting results on a wet rather than dry weight basis, greater extractability, or differences in cultivars. Minerals and fiber are generally stable to processing, storage, and cooking, but may be lost in peeling and other removal steps during processing. Mineral uptake (e.g., calcium) or addition (e.g., sodium) during processing can change the natural mineral composition of a product. Changes in fiber during processing, storage, and cooking appear to be minimal for intact fruits and vegetables. Outer layers removed or peeled products, however, contained lower amounts of fiber than their unprocessed counterparts. The stability of fiber during storage depends on commodity. Generally, fresh, frozen, and canned fruits and vegetables contained similar amounts of fiber.

Processing of fruit or vegetables can result in a significant reduction in phytochemical content. Thermal processes have a large influence in flavonoid availability in foods which depends on their magnitude and duration (Ioannou et al. 2012; Tiwari and Cummins 2013). In general, the level of phytochemicals in vegetable and fruit processing decreases exponentially with a linear increase in blanching and boiling time (Tiwari and Cummins 2013). Most of heat processes lead to a degradation of flavonoids. Thermal pasteurization treatment (90 °C, 60 s) for strawberry juices had no effect on quercetin and kaempferol contents (Odriozola-Serrano et al. 2008b), whereas it reduced naringin, narirutin, quercetin, naringenin content for grapefruit juices (Igual et al. 2011) and procyanidins in canned peach (Asami et al. 2003). Effect of pasteurization has been reported for mulberry fruit extract, pineapple juice, and cashew apple juice leading to a decrease in the levels of bioactive components such as total anthocyanin, ascorbic acid, and carotenoids (Rattanathanalerk et al. 2009; Zepka and Mercadante 2009; Aramwit et al. 2010; Rawson et al. 2011a).

Pasteurization of grape juice increased the concentration of catechins in cold-pressed juices, but it decreased concentrations in hot-pressed juices. The concentration of most procyanidins was also increased by pasteurization (Fuleki and Ricardo-Da-Silva 2003). An increase of temperature during pressing from 40 to 70 °C allows increasing flavonoid content (50 %) in apple juice (Gerard and Roberts 2004), similar results were found by Renard et al. (2011) an increase of pressing temperature from 5 to 24 °C, increase the extraction of proanthocyanidins. Van Der Sluis et al. (2002) noted that antioxidant activity of juice is lower than that of apple. The flavonoid contents were reduced due to pressing in which most flavonoids were retained in the pomace. In processing blueberries into juice, substantial losses of phenolics occurred; the recovery of anthocyanins, procyanidins, and chlorogenic acid were 32, 43, and 53 %, respectively. Heat-labile enzymes (PPO) in blueberry fruit made a large contribution to the loss in anthocyanins. Approximately 20 % of the anthocyanins in blueberries were retained in the press cake after juicing (Skrede et al. 2000). The total flavonoid content of the juices obtained by manual extraction was less than half that obtained by mechanical extraction the percentage of flavones in the juices obtained manually was always lower than in the juices extracted using industrial methods which implies a possible greater contribution of flavones from albedo and flavedo (Amarowicz et al. 2009). In juice production from concentrates, the range of thermal processing is wider and additionally includes concentration of juice. All these processes lead to decomposition of thermolabile compounds, which include antioxidants (Grajek and Olejnik 2010).

Durst and Weaver (2013) analyzed fresh freestone peaches, fresh cling peaches, and canned cling peaches for vitamins (A, C, E, folate), antioxidants, total phenolics, and total carotenoids to assess how these nutrients were affected by the canning and whether storage further changed these components. The nutritional content of canned peaches was comparable to that of fresh peaches. There were no statistically significant decreases in those nutritional parameters measured between fresh freestone peaches and canned cling peaches. Vitamins A and E along with total carotenoids decreased immediately upon processing, but stabilized after the processing step, showing minimal additional changes upon storage for 3 months. After canning of mandarin orange segments, small proportions of phenolic acids and ascorbic acid were reduced, and about half of flavanone glycosides and total antioxidant capacity were lost. However, in view of that considerable portion of phenolic compounds and ascorbic acid existing in the syrup portion, so the loss was not so significant (Fengmei et al. 2011).

During the heat treatment, the antioxidant activities of flavonoids were also slightly decreased but they remain relatively high. This is due to the fact that the degradation products possess also an antioxidant activity (Murakami et al. 2004; Buchner et al. 2006). Jeong et al. (2004) determined an increase of the antioxidant activity of citrus peels during a heat treatment (50, 100, and 150 °C for 60 min). The degradation of flavonoids is not only a function of temperature and magnitude of heating; it may depend also on other parameters such as pH, the presence of oxygen, and the presence of other phytochemicals in the medium (Ioannou et al. 2012). Degradation of rutin and quercetin is higher under weakly alkaline and neutral reaction conditions (Takahama 1986; Buchner et al. 2006). The presence of oxygen highly induces

quercetin and rutin degradations, while the absence of oxygen has the opposite effects (Makris and Rossiter 2000; Buchner et al. 2006). Moreover, the presence of other phytochemicals in the medium like chlorogenic acid plays a protective role (Murakami et al. 2004).

According to Turkmen et al. (2005), food processing and domestic cooking led to an increase in phenol concentration when compared to raw samples. This suggested that temperature-related treatments might produce changes in antioxidant extractability, not only for cellular disruption and dissociation of some phenolic compounds from biological structures but also for the alteration in their chemical structure which could make possible the conversion of insoluble phenolics into more soluble forms (Cohen et al. 2001; Bernhardt and Schlich 2006; Dini et al. 2013).

Processing of strawberries into jam may result in a loss of up to 70 % of the initial anthocyanin content (García-Viguera et al. 1999). Jams produced from various strawberry cultivars differed in terms of pigment and antioxidant capacity retention. Temperature proved to be the most important factor during storage (Wicklung et al. 2005). Brownmiller et al. (2008) determined a reduction of about 43 % in total anthocyanins in purees following blanching and pasteurization comparing to the original levels found in fresh blueberries. Losses of about 23 % of flavonoids were reported in the blackberry juice. Especially blanching, drastically reduced anthocyanins, whereas hot-filling degraded ellagitannins (Gancel et al. 2011). In some cases thermally processed fruits are shown to have higher levels of phytochemicals (Tiwari and Cummins 2013). For instance, Zafrilla et al. (2001) noted that a 2.5-fold increase in free ellagic acid content during the processing of raspberry jams. They suggested that it could be due to the hydrolytic breakdown of ellagitannins to ellagic acid during thermal treatment. In some cases, blanching inactivates enzymes such as PPO, which improves the stability of anthocyanins in processed food. Leong and Oey (2012) evaluated the effects of heating (98 °C, 10 min), freezing (−20 °C), and freeze-drying on anthocyanins, carotenoids, and vitamin C content of cherries, nectarines, apricots, peaches, plums, carrots, and red bell peppers. In most cases, heating increased the anthocyanin content in cherries, peaches, and plums but not in nectarines. It was determined that the heated fruits contained more anthocyanins than the fresh fruits. However, heating decreased the content of carotenoids in apricots, nectarines, and carrots while maintaining the carotenoid content in cherries, peaches, plums, and red bell peppers.

The production of tomato paste from fresh tomatoes involves mechanical homogenization and heat treatment. In this process, bioavailability of β-carotene and lycopene is enhanced, but other labile antioxidants are destroyed. The increase in carotenoids is due to enzymatic degradation, weakening of protein-carotenoid aggregates, and concentration of dry matter during evaporation (Van Boekel et al. 2010). However, conflicting data on tomato carotenoid stability during thermal processing of tomato can be found in the literature. For instance, Capanoglu et al. (2008) showed a significant decrease in the content of both lycopene (32 %) and β-carotene (36 %) during preparation of a tomato paste.

Drying processes lead to flavonoids degradation. The proportion lost depends on the drying method. Freeze-drying is the less aggressive method, whereas hot air drying leads to major losses. As intermediate solutions, microwave and vacuum drying

can be used (Zainol et al. 2009; Zhang et al. 2009; Dong et al. 2011; Ioannou et al. 2012). Microwaves directly interact with food and heat is generated volumetrically. Short processing time in microwave drying, sterilization, and thawing is advantageous to reduce quality losses especially for perishable food products (Sumnu and Sahin 2005). Microwave treatments produced small modifications of the quantitative and qualitative composition of carotenoids in papaya and anthocyanins in strawberry. Chlorophylls in kiwi fruit showed significant degradation as a consequence of microwave heating (De Ancos et al. 1999). Igual et al. (2012) compared the drying kinetics and the change in the organic acids, phenolic compounds, and antioxidant activity of dried apricot when using hot air drying and microwave energy. The authors noted that the industrial processing of dried apricots may be improved by using microwave energy, as the drying time is considerably reduced, and the obtained fruit had a higher phenolic content, particularly of chlorogenic acid, catequin, and epicatequin. Nevertheless, as the contribution of these phenols to antioxidant capacity was not significant, microwave dried samples maintained the same antioxidant capacity as the air-dried ones. Fast development allowed new hybrid solutions like microwave-hot air-drying, microwave-vacuum drying, microwave-spouted bed drying, and microwave-halogen lamp drying. These methods allow reduced drying time and maintenance of the high nutritive quality of products (Grajek and Olejnik 2010).

Comparative studies on freeze-drying and hot air-drying of tomatoes showed that freeze-drying retained high levels of antioxidant compounds (8–10 % loss), whereas high temperature treatment caused a tremendous decrease in the content of antioxidants (56–61 % loss) (Chang et al. 2006). Interestingly, the total phenolic and flavonoid contents in both freeze and hot-air-dried tomatoes were significantly higher than in fresh material. Different changes appeared in lycopene content. In freeze-dried tomatoes, lycopene content was reduced by 33–48 %; however, the amounts of lycopene in hot-air-dried tomatoes increased 152–197 %, probably due to breaking of cell walls and weakening of the binding forces between lycopene and the tissue matrix (Grajek and Olejnik 2010).

Compared to heating, freezing could maintain or slightly increase the content of phytochemicals for most of the commodities. Freezing induces the formation of ice crystals that favors localized concentration of solutes (including phytochemicals) and reallocation of water molecules in the cell structure. Nevertheless, the common consequences of freezing due to cell damages by the growth of ice crystals from temperature fluctuation and turgor loss lead to softening texture (Szczesniak 1998). It is noted that the rate of freezing influences the ice crystals formation that impact on the food structure by expanding the separation between cells. In other words, when the samples were rapidly frozen, large amounts of smaller ice crystals formed and caused a lesser degree of cell structure disruption than the samples being frozen slowly, which formed large intercellular ice crystals (Leong and Oey 2012). In general, the manner in which the frozen sample is thawed is a key factor that will attribute to the changes in phytochemical contents (Robards 2003). In contrast, freeze-dried samples mostly resulted in a lower amount of phytochemicals, as compared to fresh, heated, and frozen commodities. Basically, freeze-drying is the combination of dehydration and freezing, i.e., dehydrating the samples by freezing the immobilized water into ice

and then removing the ice crystals via sublimation into vapor. While freeze-drying is incapable of inactivating all of the enzymes, it is effective in preserving the sensory and nutritional qualities. Usually, a minor loss of vitamin does occur but extensive reduction of water during freeze-drying will form the fragile porous structure in the end product. Sublimation of ice to vapor caused by drying in the sample slices gave an open and porous texture. The heat utilization in freeze-drying may be harsher than the conventional freezing mechanism as the flavor and aroma compounds were evaporated along with water as volatiles. In practice, thinly sliced samples were used to promote larger surface area available for dehydration had increased the water removal rate. Nevertheless, the phytochemicals in freeze-dried samples were more prone to degradation due to the large surface area exposed during processing. Hence, most of the labile phytochemicals were rapidly oxidized, because the water molecules attached on the sample surface that acted as a protecting film were evaporated as well (Gross 1991; Leong and Oey 2012). Georgé et al. (2011) determined the impact of thermal processing and lyophilization on carotenoids, total polyphenols, and vitamin C in red and yellow tomato cultivars. Micronutrients were analyzed in fresh tomatoes, tomato purée, and lyophilized tomatoes. Processing did not affect the carotenoid content in red tomato, but significantly lowered β-carotene in yellow tomato and also the contents of total polyphenol and vitamin C in both cultivars. Lyophilization lowered the carotenoid content in red tomato but not in yellow tomato; in contrast, the total polyphenol content was preserved in red tomato but lowered in yellow tomato, and the vitamin C content was not affected in both cultivars. Arancibia-Avila et al (2012) determined that the antioxidant activity of lyophilized berry samples subjected to thermal processing at 100 °C for 10 and 20 min did not differ from the non-processed berries, showing high correlation between the total polyphenols, flavanols, and the antioxidant activities. It was found that berries subjected to thermal processing not more than 20 min maximally preserved the bioactivity.

Ohmic heating, also called electric resistance heating, is a direct heating method in which the food itself is a conductor of electricity, taken from the mains that are 50 Hz in Europe and 60 Hz in the USA. It provides rapid and uniform heating, resulting in less thermal damage to the product (Ramaswamy and Chen 2002; Icier and Ilicali 2005; Leizerson and Shimoni 2005). Vikram et al. (2005) reported that the smallest losses of vitamin C were observed in the ohmic-heated orange juices. The highest losses of vitamin C were observed during microwave heating due to uncontrolled temperature generated during processing. Lee et al. (2012) evaluated the efficacy of continuous ohmic heating for inactivating *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Listeria monocytogenes* in orange and tomato juices with various treatment times and electric field strengths (25–40 V cm^{-1}). The concentration of vitamin C in continuous ohmic-heated orange juice was significantly higher than in conventionally heated orange juice. It was suggested that continuous ohmic heating might be effectively used to pasteurize fruit and vegetable juices in a short operating time and that the effect of inactivation depends on applied electric field strengths, treatment time, and electric conductivity. Yildiz et al. (2009) demonstrated that ohmic heating did not cause any different effect in other quality indices and total phenolic contents of pomegranate juice than the conventional heating.

4.2 Nonthermal Processing

Nonthermal technologies are effective at sublethal temperatures, thereby minimizing negative thermal effects on phytochemicals. Several nonthermal techniques such as high pressure processing (HPP), pulsed electric field (PEF), ultrasound/sonication, and ultraviolet (UV) techniques have been investigated on fruit and vegetables and their products (Tiwari et al. 2009a). Recent interests in these technologies are not only to obtain high quality food with "fresh-like" characteristics but also to provide food with improved functionalities (Rawson et al. 2011a).

When innovative processes are used instead of thermal treatments, the importance of food matrix is lower because the flavonoid degradations are limited (Ioannou et al. 2012). Several studies reported the capacity of innovative processes (microwave, infra-red, high-pressure processing) to enhance the flavonoid extraction (Périno-Issartier et al. 2010; Srinivas et al. 2011; Zill et al. 2011). Odriozola-Serrano et al. (2008b) studied the effect of high-intensity pulsed electric fields (HIPEF) process on quercetin and kaempferol contents of strawberry juices and reported that such a process caused no damage on these compounds.

4.2.1 High Hydrostatic Pressure Processing (HHP)

HHP entails the transmission of pressures usually ranging from 300 to 700 MPa to foods, which results into a reduction of microbial loads and thus shelf life extension (Patras et al. 2009a). High hydrostatic pressure (HHP) treatment is considered to be an alternative to thermal pasteurization for fruit and vegetable juices. HHP treatment could preserve nutritional value and the sensory properties of fruits and vegetables due to its limited effect on the covalent bonds of low molecular mass compounds such as color, flavor compounds, and vitamins. HHP processing may enhance the antioxidant activity of juices comparing to those untreated. However, inactivation of important foodborne pathogens in low acid foods by HHP is most urgent and critical (Oey et al. 2008; Garcia-Parra et al. 2011; Pilavtepe-Celik 2013; Uckoo et al. 2013).

Huang et al. (2013) investigated the effects of (HHP) at 300–500 MPa for 5–20 min and high temperature short time (HTST) at 110 °C for 8.6 s on enzymes, phenolics, carotenoids, and color of apricot nectars. Micronutrients and phytochemicals of nectar were well preserved by both HHP and HTST. Compared with HHP treatment (500 MPa/20 min), HTST led to complete inactivation of enzymes, higher total phenolics, epicatechin, ferulic acid, and p-coumaric acid and lighter and more intensity color than those of HHP treatment, since HTST treatment gave better impact on the quality of apricot nectar. PPO, peroxidase, and pectinmethylesterase in apricot nectar were found to be highly resistant to high pressure inactivation, thus in order to maintain the quality of apricot nectar, HHP should be accompanied by additional measures.

Sanchez-Moreno et al. (2003) measured vitamin C, provitamin A carotenoids, and other carotenoids in freshly squeezed juices from oranges that were subjected to HHP.

Total carotenoids and vitamin A (expressed as retinol equivalents) showed an increasingly better extraction when the pressure increased from 100 to 400 MPa. Vitamin C content seems to preserve the carotenoid compounds from oxidation in the treated orange juices. Fernández-García et al. (2001) reported that the vitamin C content of orange and orange–carrot–lemon juices processed at 500 and 800 MPa was not, or only insignificantly, reduced compared to that of unprocessed juices. Vitamin B1, B2, B3, and B6 contents were not changed after pressurizing orange juice (Donsi et al. 1996). In orange juice and kiwi puree, folic acid was relatively pressure stable, in contrast to that in carrot juice (Indrawati et al. 2004). Different folate stabilities among orange juice, kiwi puree, carrot juice, and asparagus seemed to coincide with different levels of ascorbic acid content.

Ferrari et al. (2010) studied the effects of high pressures (400–600 MPa) at 25, 45, 50 °C for 5 or 10 min on phytochemical content of pomegranate juice. Their experimental results indicated that the content of anthocyanins was influenced mainly by pressure and temperature level. At room temperature, the concentration of these molecules decreases with the intensity of the treatment in terms of pressure level and processing time. Therefore, the higher pressure levels or longer processing times caused a decrease of the anthocyanin content. High pressure treatments modified the mechanism of anthocyanin degradation by affecting the enzymes involved in the kinetics of reaction. The residual activity of the enzymes along with a small concentration of dissolved oxygen could cause the degradation of the anthocyanins during the storage of the processed juice.

Keenan et al. (2010) assessed the effect of thermal and HHP on the antioxidant activity and phenolic content of fruit smoothies. Since decreases in levels of antioxidants were noted during long-term storage, it would appear that higher pressure treatments (>450 MPa) might be required for better retention of antioxidant compounds in fruit smoothies. HHP processing of smoothies at moderate temperatures may be a suitable alternative to traditional thermal processing (Keenan et al. 2012). Patras et al. (2009b) reported that levels of phenols increased significantly in HHP treated (600 MPa, 20 °C, 15 min) strawberry and blackberry purees (9.8 and 5.0 %, respectively).

Briones-Labarca et al. (2011) investigated the effect of high pressure on the bioaccessibility of specific nutrients (antioxidant, minerals and starch) in apple. They reported that high pressure processed apple had significantly higher antioxidant capacities, mineral, and starch content when compared to untreated samples. It is possible that changes to the tissue matrix induced by HHP, for example, disruption of the plant cell walls, resulted in the release of compounds with antioxidant actions and increased mineral and starch content into the extracellular environment. Consumption of apple under high hydrostatic pressure may supply substantial antioxidants, minerals, and starch which may provide health promoting and disease preventing effects.

Varma et al. (2010) reported that HHP processing causes conformational changes from the all *trans* to *cis* isomer form of lycopene, indicating that high pressure application can induce isomerization, increasing the availability of the carotenoids in the sample.

Nuñez-Mancilla et al. (2013) analyzed the effects of combined osmotic dehydration and high hydrostatic pressure on physicochemical and quality parameters (color, antioxidant capacity, total phenolic content, and vitamin C) on strawberries stored at 5 °C. The results indicated that quality profiles of strawberry osmotically dehydrated under high hydrostatic pressure between 300 and 500 MPa showed minimal differences when compared to untreated samples. For this reason, it was recommended working at 400 MPa/10 min to obtain processed strawberries with high levels of both nutritional and antioxidant characteristics.

Distinct from the application of HHP for preservation purposes, high pressure treatments have been used to extract secondary plant metabolites from fruits and vegetables. For example, De Ancos et al. (2000) successfully applied HHP (50–400 MPa, 25 °C/15 min) processing to extract carotene from persimmon fruit purees. Different pressure levels at constant temperature gave different release of various carotenes depending on their chemical properties and chromoplast location. The use of high pressure enhances mass transfer rates, which increases cell permeability as well as secondary metabolite diffusion (Dornenburg and Knoor 1993). HHP treatment influences the phytochemical stability and the extraction yield of bioactive compounds. As a consequence, changes in antioxidant activity could also occur during HHP treatment (Rawson et al. 2011a).

4.2.2 Pulsed Electric Field (PEF)

PEF is a technology that has been extensively investigated in recent years for its applications in food processing. PEF pasteurization is a technique based on the delivery of pulses at high electric field intensity (5–55 kV cm^{-1}) to a food in the millisecond range (Lado and Yousef 2002). By the mechanism of electropermeabilization, pulsed electrical fields have proved a valid technology for the production of safe beverage products and shown a positive influence in the texture of solid plant foods, leading to enhanced yields of extraction of metabolites, as well as increased juice yields (Rawson et al. 2011a).

Morales-de la Peña et al. (2010a, b) investigated the effect of PEF on vitamin C in orange/kiwi/pineapple, and soymilk-based beverage immediately after treatment and noted that levels were not different from the thermally processed juice. However, the beneficial effect of the PEF treatment was noticeable over a storage period of 31 days, as an 800 μs treatment at 35 kV/cm showed significantly greater retention than both 1,400 μs treatment and thermal treatment. These results showed that the shorter the PEF treatment time, the higher the vitamin C retention, as previously found in other studies focused on individual fruit juices treated by high intensity PEF (HIPEF). In general, longer exposure PEF treatment times may induce reduction in the retention of vitamin C due to product heating. Longer exposure time may also generate free radicals which may speed up vitamin C degradation. Moreover, the antioxidant capacity of this product during storage decreased to a greater degree in thermally treated samples than in PEF treated samples after a storage period of 60 days.

PEF can retain higher levels of phenolic compounds in fruit juices and improve their stability during storage. Odriozola-Serrano et al. (2008b) observed significantly less phenolic degradation by PEF (49 %) than by thermal pasteurization (55 %) after 56 days of storage of strawberry juice.

Studies evaluating the effects of HIPEF processing conditions on watermelon juices have been demonstrated that HIPEF treatments were effective in reducing the population of pathogenic microorganisms and inactivating spoilage enzymes. Watermelon juice exhibited high retention of lycopene and antioxidant capacity when high electric field strengths, frequencies, and pulse widths were applied. However, severe HIPEF treatments reduced vitamin C content. Maximal relative lycopene content (113 %), vitamin C (72 %), and antioxidant capacity retention (100 %) were obtained when HIPEF treatments were set up at 35 kV/cm for 50 μs using 7 μs bipolar pulses at 200 Hz (Aguiló-Aguayo et al. 2008; Oms-Oliu et al. 2009).

Vervoort et al. (2011) compared the impact of thermal, HHP, and PEF processing for mild pasteurization of orange juice, using processing conditions leading to an equivalent degree of microbial inactivation. Their study provided evidence that HHP and PEF pasteurization do not cause any significant differences in the major components regarding public health that were investigated, in comparison to thermal pasteurization, and therefore no changes in the human metabolism after consumption are to be expected.

4.2.3 Ultrasound

Ultrasound is used at frequencies in the range of 20–100 kHz and requires the presence of a liquid medium for power transmission. It causes chemical and physical changes in biological structures (in a liquid medium) due to intracellular cavitation (Alexandre et al. 2012). In last decade power ultrasound has emerged as an alternative processing option to conventional thermal approaches for pasteurization and sterilization of food products. Ultrasound processing on its own or in combination with heat and/or pressure is an effective processing tool for microbial inactivation and phytochemical retention. Advantages of ultrasound include reduced processing time, higher throughput, and lower energy consumption (Zenker et al. 2003; Rawson et al. 2011a).

Ultrasound treatment of fruit juices is reported to have a minimal effect on the ascorbic acid content during processing and results in improved stability during storage when compared to thermal treatment. This positive effect of ultrasound compared with heating is assumed to be due to the effective removal of occluded oxygen from the juice (Knorr et al. 2004). Ascorbic acid content was found to be significantly higher in guava juice samples treated with carbonation and sonication than in the control. It could be due to cavitation effects caused by carbonation and sonication (Cheng et al. 2007). However, degradation of vitamin C in sonicated orange, strawberry, and tomato juices was observed and the degradation level

depended on the wave amplitude and treatment time. Ascorbic acid degradation during sonication may be due to free radical formation and production of oxidative products on the surface of bubbles (Tiwari et al. 2009b, c).

Ultrasonication may be considered a potential technology for processing of red juices because of its minimal effect on anthocyanins (Oms-Oliu et al. 2012). Tiwari et al. (2009a) reported a slight increase (1–2 %) in the pelargonidin-3-glucoside content of the juice at lower amplitude levels and treatment times which may be due to the extraction of bound anthocyanins from the suspended pulp.

Ultrasonic extraction is a well-known commercial method to increase mass transfer rate by cavitation forces. Bubbles in the liquid–solid extraction using ultrasonic extraction can explosively collapse and produce localized pressure, improving the interaction between the intracellular substances and the solvent to facilitate the extraction of the phytochemicals (Saldana et al. 2010). The extraction of lycopene from tomato using ultrasonic-assisted extraction and ultrasound/microwave-assisted extraction was reported (Lianfu and Zelong 2008). Rawson et al. (2011b) determined that sonication temperature played a significant role in preservation of bioactive compounds. Freshly squeezed watermelon juice was subjected to thermosonication treatments with processing variables of temperature (25–45 °C), amplitude level (24.1–60 μm), and processing time (2–10 min) at a constant frequency of 20 kHz and pulse durations of 5 s on and 5 s off. They observed a decrease in the phenolic content of sonicated watermelon juice when the temperature was increased from 25 to 45 °C. Temperature effect was more pronounced at higher processing times.

4.2.4 Radiation Processing

Irradiation treatment generally involves the exposure of food products (raw or processed) to ionizing or non ionizing radiation for the purpose of food preservation. The ionizing radiation source could be high-energy electrons, X-rays, or gamma rays, while the non ionizing radiation is electromagnetic radiation that does not carry enough energy/quanta to ionize atoms or molecules, represented mainly by ultraviolet rays (UV-A: 315–400 nm, UV-B: 280–315 nm, and UV-C: 100–280 nm), visible light, microwaves, and infrared (Prakash et al. 2000; Rawson et al. 2011a). Food irradiation is a physical treatment in which food is exposed to ionizing radiation, i.e., radiation of sufficient energy to expel electrons from atoms and to ionize molecules. Foods treated with ionizing radiation have consistently been shown to be wholesome and nutritious. The effect of irradiation on vitamins has been studied extensively. Sugars may be hydrolyzed or oxidized when subjected to gamma radiation. Free amino acids can be deaminated. Free radicals react with polyunsaturated fatty acids, producing unstable hydroperoxides and a range of further degradation products. Certain vitamins (A, B1, B12, C, E, K), particularly those with antioxidant activity, are degraded when irradiation is carried out in the presence of oxygen (Niemira and Deschênes 2005).

Alighourchi et al. (2008) reported a significant reduction in the total and individual anthocyanin content in pomegranate juice after irradiation at higher doses (3.5–10 kGy). Irradiation effects on anthocyanin pigments depend upon the nature of anthocyanin, for example, diglycosides are relatively stable toward irradiation dose compared to monoglycosides. Reyes and Cisneros-Zevallos (2007) investigated the effect of irradiation (1–3.1 kGy) on mango. The authors did not find a significant impact of irradiation dose on the total phenolic content, while there was a significant increase in flavonols after 18 days storage period for the irradiated fruits (at 3.1 kGy). In contrast, ascorbate content of the fruits decreased when the dose exceeded 1.5 kGy. No major changes in the carotenoids content were recorded. In general, the decrease in antioxidant compounds is attributed to the formation of radiation-induced degradation products or the formation of free radicals (Wong and Kitts 2001; Sajilata and Singhal 2006). The effects of harvest date, storage, and low-dose irradiation on flavanones were investigated in grapefruits. In general; flavanone concentrations increased with increasing irradiation dose even in the late season grapefruit, and storage had a positive effect on flavanone levels (Patil et al. 2004).

It has been reported that irradiation treatments can generate free radicals, thus leading to an induction of stress responses in plant foods, which in turn may lead to an increase in the antioxidant synthesis (Oms-Oliu et al. 2012). Song et al. (2006) observed that total phenolic content of carrot and kale juices substantially increased by applying an irradiation treatment. However, reductions in the total phenolic content have been reported for treatments of more than 10 kGy in some irradiated products (Villavicencio et al. 2000; Ahn et al. 2005).

Irradiation of plant tissues with UV has been shown to have positive interactions, indicating an increase in the enzymes responsible for flavonoid biosynthesis, affecting plant phenolic metabolites apart from induction of abiotic stress. UV-A has been reported to induce anthocyanin biosynthesis in fruits encompassing cherries (Kataoka et al. 1996).

UV-C is the most common applied to fresh fruits and vegetables, since it acts directly or indirectly as an antimicrobial agent. UV-C can cause direct bacterial DNA damage or may induce resistance mechanisms against pathogens in different fruits and vegetables. Low doses of UV-C radiation (254 nm) also reduce decay of a wide range of fruits and vegetables when applied after harvest (Ben-Yehoshua and Mercier 2005; Ramos et al. 2013). Erkan et al. (2008) investigated the changes in antioxidant capacity, enzyme activity, and decay development in strawberry fruit illuminated with different UV-C dosages. Three UV-C illumination durations and dosages, 1, 5, and 10 min (0.43, 2.15, and 4.30 kJ m^{-2}) tested promoted the antioxidant capacity and enzyme activities and significantly reduced the severity of decay during storage at 10 °C compared to the control. All UV-C dosages increased the phenolic content of strawberry fruits as well. Total anthocyanin content increased during storage in all treatments.

Like PEF treatment, UV exposure can kill microorganisms with potentially less impact on food quality (Chen et al. 2013). UV irradiation has proved to be effective against *E. coli* O157:H7 in unpasteurized apple cider (Hanes et al. 2002; Basaran et al. 2004). Guerrero-Beltrán et al. (2009) evaluated the UV-C light effect

on *Saccharomyces cerevisiae* inactivation in grape, cranberry, and grapefruit juices. The maximum log reduction (cfu/mL) was 0.53, 2.51, and 2.42 for yeast count in grape, cranberry, and grapefruit juices, respectively, after 30 min of UV light treatment at the maximum flow rate (1.02 L/min).

Noci et al. (2008) reported that UV exposure of apple juice caused a 29 % reduction in total phenolic content, which was much lower than that due to thermal processing (48 %). However, UV exposure has its limitations when treating juices. UV light only penetrates a very short depth into the surface of a juice when compared with clear water (Lu et al. 2010). The penetration of UV light into juices is about 1 mm for absorption of 90 % of the light. As a result, a special conduction of the liquid flow is always used in the UV exposure of juices to minimize the absorption. Lu et al. (2010) designed a small thin film UV reactor to process apple juice with the aim of increasing the microbial inactivation rate and reported its excellent performance in the reduction of microorganisms in various apple juices. The apple juice stability and nutritional qualities were also improved by using this method.

In particular, the combination of UV and PEF as a hurdle may overcome the limitations of the individual techniques and has proven to be more effective for microbial inactivation and maintaining nutritional quality of fruit juice (Chen et al. 2013).

4.2.5 Membrane Filtration

Reverse osmosis (RO) and ultrafiltration (UF) are both unit operations in which water and some solutes in a solution are selectively removed through a semipermeable membrane. They are similar in that the driving force for transport across the membrane is the pressure applied to the feed liquid. However, RO is used to separate water from low-molecular-weight solutes (e.g., salts, monosaccharides, and aroma compounds), which have a high osmotic pressure. A high pressure, 5–10 times that is used in UF (4,000–8,000 $\times 10^3$ Pa), is therefore necessary to overcome this. Microfiltration (MF) is similar to UF in using lower pressures than RO, but is distinguished by the larger range of particle sizes (0.01–2 μm) that are separated (Fellows 2000).

UF and MF are the most commonly used membrane filtration techniques for fruit juice processing. They have been applied commercially for the clarification of fruit juices. Basically, the membranes retain large molecules such as microorganisms, lipids, proteins, and colloids (UF only) and allow small molecules such as vitamins, salts, sugars, and water to flow through them. Therefore, via this process, "cold pasteurized" products (>5 log reduction or removal of microorganisms) can be produced with better flavors than thermally treated products (Cassano et al. 2003; Rektor et al. 2004; Chen et al. 2013). In contrast to concentration by boiling, RO and UF membranes concentrate foods without heat to produce good retention of sensory and nutritional qualities (Fellows 2000).

Pap et al. (2010) applied reverse osmosis process for the concentration of black currant juice. The researchers reported that enzymatic treatment resulted in the increase of anthocyanin and flavonol content of the juices. The centrifugation process decreased the amount of anthocyanins and flavonols to some extent.

The juice clarified by UF had significantly lower concentrations of anthocyanins and flavonols, while enzymatic pretreatment applied juice had the highest levels of these flavonoids. Enzymatic pretreatment improved the permeate flux in RO during the concentration process and resulted in a juice concentrates highest in anthocyanins and flavonols.

A comparative study by Cassano et al. (2003) on the concentration of blood, orange juice demonstrated that the total antioxidant activity of juice concentrated by evaporation was lower than that of the fresh juice. During UF, the total antioxidant activity was maintained in both permeate and retentate. When RO was applied, a small decrease of the total antioxidant activity was determined. Osmotic distillation, applied as subsequent concentration step after RO, did not cause any significant loss in antioxidant activity of the juice. Cassano et al. (2006) proposed integrated membrane process for the production of kiwifruit juice. Losses of total antioxidant activity after UF and osmotic distillation relative to the fresh juice were 4.4 and 11.1 %, respectively, and the reduction of vitamin content in the final concentrate was also very limited.

References

Aaby K, Wrolstad RE, Ekeberg D, Skrede G (2007) Polyphenol composition and antioxidant activity in strawberry purees; impact of achene level and storage. J Agric Food Chem 55(13):5156–5166

Aguiló-Aguayo I, Soliva-Fortuny R, Martín-Belloso O (2008) Effects of thermal and high-intensity pulsed electric field treatments on quality related enzymes of watermelon juices. In IFT annual meeting, paper 135-03, New Orleans, USA

Ahn HJ, Kim JH, Kim JK, Kim DH, Yook HS, Byun MW (2005) Combined effect of irradiation and modified atmosphere packaging on minimally processed Chinese cabbage (*Brassica ropa* L.). Food Chem 89:589–597

Aked J (2002) Maintaining the post-harvest quality of fruits and vegetables. In: Jongen W (ed) Fruit and vegetable processing: improving quality. Woodhead Publishing and CRC Press, Boca Raton

Alexandre EMC, Brandão TRS, Silva CLM (2012) Efficacy of non-thermal technologies and sanitizer solutions on microbial load reduction and quality retention of strawberries. J Food Eng 108(3):417–426

Alighourchi H, Barzegar M, Abbasi S (2008) Effect of gamma irradiation on the stability of anthocyanins and shelf-life of various pomegranate juices. Food Chem 110:1036–1040

Amarowicz R, Carle R, Dongowski G, Durazzo A, Galensa R, Kammerer D, Maiani G, Piskula MK (2009) Influence of postharvest processing and storage on the content of phenolic acids and flavonoids in foods. Mol Nutr Food Res 53:S151–S183

Amin I, Norazaidah Y, Hainida KIE (2006) Antioxidant activity and phenolic content of raw and blanched Amaranthus species. Food Chem 94:47–52

Aramwit P, Bang N, Srichana T (2010) The properties and stability of anthocyanins in mulberry fruits. Food Res Int 43:1093–1097

Arancibia-Avila P, Namiesnik J, Toledo F, Werner E, Martinez-Ayala AL, Rocha-Guzmán NE, Gallegos-Infante JA, Gorinstein S (2012) The influence of different time durations of thermal processing on berries quality. Food Control 26:587–593

Asami DK, Hong YJ, Barrett DM, Mitchell AE (2003) Processing-induced changes in total phenolics and procyanidins in clingstone peaches. J Sci Food Agric 83:56–63

Ayala-Zavala JF, Wang SY, Wang CY, González-Aguilar GA (2005) Methyl jasmonate in conjunction with ethanol treatment increases antioxidant capacity, volatile compounds and postharvest life of strawberry fruit. Eur Food Res Technol 221(6):731–738

Ayala-Zavala JF, Wang SY, Wang CY, González-Aguilar GA (2007) High oxygen treatment increases antioxidant capacity and postharvest life of strawberry fruit. Food Technol Biotechnol 45(2):166–173

Ayala-Zavala JF, Del-Toro- Sánchez L, Alvarez-Parrilla E, González-Aguilar GA (2008a) High relative humidity in-package of fresh-cut fruits and vegetables: advantage or disadvantage considering microbiological problems and antimicrobial delivering systems? J Food Sci 73(4):R41–R47

Ayala-Zavala JF, Del-Toro-Sánchez L, Alvarez-Parrilla E, Soto-Valdez H, Martin-Belloso O, Ruiz-Cruz S, González-Aguilar GA (2008b) Natural antimicrobial agents incorporated in active packaging to preserve the quality of fresh fruits and vegetables. Stewart Postharvest Rev 4:1–9

Balla C, Farkas J (2006) Minimally processed fruits and fruit products and their microbiological safety. In: Hui YH (ed) Handbook of fruits and fruit processing. Blackwell Publishing, Hoboken

Basaran N, Quintero-Ramos A, Moake MM, Churey JJ, Worobo RW (2004) Influence of apple cultivars on inactivation of different strains of *Escherichia coli* O157:H7 in apple cider by UV irradiation. Appl Environ Microbiol 70:6061–6065

Ben-Yehoshua S, Mercier J (2005) UV irradiation, biological agents, and natural compounds for controlling postharvest decay in fresh fruits and vegetables. In: Ben-Yehoshua S (ed) Environmentally friendly technologies for agricultural produce quality. Taylor & Francis, Boca Raton

Bernhardt S, Schlich E (2006) Impact of different cooking methods on food quality: retention of lipophilic vitamins in fresh and frozen vegetables. J Food Eng 77:327–333

Briones-Labarca V, Venegas-Cubillos G, Ortiz-Portilla S, Chacana-Ojeda M, Maureira H (2011) Effects of high hydrostatic pressure (HHP) on bioaccessibility, as well as antioxidant activity, mineral and starch contents in Granny Smith apple. Food Chem 128:520–529

Brownmiller C, Howard LR, Prior RL (2008) Processing and storage effects on monomeric anthocyanins, percent polymeric color, and antioxidant capacity of processed blueberry products. J Food Sci 73:72–79

Buchner N, Krumbein A, Rhon S, Kroh LW (2006) Effect of thermal processing on the flavonols rutin and quercetin. Rapid Commun Mass Spectrom 20:3229–3235

Burri J, Bertoli C, Stadler RH (2009) Food processing and nutritional aspects. In: Stadle RH, Lineback DR (eds) Process-induced food toxicants: occurrence, formation, mitigation, and health risks. Wiley, Hoboken

Capanoglu E, Beekwilder J, Boyacioglu D, Hall R, De Vos R (2008) Changes in antioxidant and metabolite profiles during production of tomato paste. J Agric Food Chem 56(3):964–973

Cassano A, Drioli E, Galaverna G, Marchelli R, Di Silvestro G, Cagnasso P (2003) Clarification and concentration of citrus and carrot juices by integrated membrane processes. J Food Eng 57:153–163

Cassano A, Figoli A, Tagarelli A, Sindona G, Drioli E (2006) Integrated membrane process for the production of highly nutritional kiwifruit juice. Desalination 189:21–30

Chang CH, Lin HY, Chang CY, Liu YC (2006) Comparison on the antioxidant properties of fresh, freeze-dried and hot-air-dried tomatoes. J Food Eng 77:478–485

Chen Y, Yu LJ, Vasantha Rupasinghe HP (2013) Effect of thermal and non-thermal pasteurisation on the microbial inactivation and phenolic degradation in fruit juice: a mini-review. J Sci Food Agric 93:981–986

Cheng LH, Soh CY, Liew SC, Teh FF (2007) Effects of sonication and carbonation on guava juice quality. Food Chem 104(4):1396–1401

Cohen MF, Sakihama Y, Yamasaki H (2001) Roles of plant flavonoids in interactions with microbes: from protection against pathogens to mediation of mutualism. In: Pandalai SG (ed) Recent research developments in plant physiology. Research Signpost, Trivandrum

Cui X, Shang Y, Shi Z, Xin H, Cao W (2009) Physicochemical properties and bactericidal efficiency of neutral and acidic electrolyzed water under different storage conditions. J Food Eng 91(4):582–586

De Ancos B, Cano MP, Hernandez A, Monreal M (1999) Effects of microwave heating on pigment composition and colour of fruit purees. J Sci Food Agric 79:663–670
De Ancos B, Gonzalez E, Pilar Cano M (2000) Effect of high pressure treatment on the carotenoid composition and the radical scavenging activity of persimmon fruit purees. J Agric Food Chem 48:3542–3548
Dini I, Tenore GC, Dini A (2013) Effect of industrial and domestic processing on antioxidant properties of pumpkin pulp. LWT Food Sci Technol 53:382–385
Domingo JL, Gine Bordonaba J (2011) A literature review on the safety assessment of genetically modified plants. Environ Int 37:734–742
Dong J, Ma X, Fu Z, Guo Y (2011) Effects of microwave drying on the contents of functional constituents of *Eucommia ulmoides* flower tea. Ind Crops Prod 34(1):1102–1110
Donsi G, Ferrari G, Di Mateo M (1996) High pressure stabilization of orange juice: evaluation of the effects of process conditions. Italian J Food Sci 2:99–106
Dornenburg H, Knoor D (1993) Cellular permeabilization of cultured plant tissues by high electric field pulses or ultra high pressure for the recovery of secondary metabolites. Food Biotechnol 7:35–48
Durst RW, Weaver GW (2013) Nutritional content of fresh and canned peaches. J Sci Food Agric 93:593–603
Dziezak JD (1986) Preservative systems in foods, antioxidants and antimicrobial agents. Food Technol 40:94–136
Erkan M, Wang SY, Wang CY (2008) Effect of UV treatment on antioxidant capacity, antioxidant enzyme activity and decay in strawberry fruit. Postharvest Biol Technol 48:163–171
Fellows P (2000) Food processing technology principles and practice. Woodhead, Cambridge
Fengmei Z, Liangbin H, Guihua X, Quanxian C (2011) Changes of some chemical substances and antioxidant capacity of mandarin orange segments during can processing. Procedia Environ Sci 11:1260–1266
Fernández-García A, Butz P, Bognár A, Tauscher B (2001) Antioxidative capacity, nutrient content and sensory quality of orange juice and an orange-lemon-carrot juice product after high pressure treatment and storage in different packaging. Eur Food Res Technol 213:290–296
Ferrari G, Maresca P, Ciccarone R (2010) The application of high hydrostatic pressure for the stabilization of functional foods: pomegranate juice. J Food Eng 100:245–253
Fuleki T, Ricardo-Da-Silva JM (2003) Effects of cultivar and processing method on the contents of catechins and procyanidins in grape juice. J Agric Food Chem 51:640–646
Gancel AL, Feneuil A, Acosta O, Pérez AM, Vaillant F (2011) Impact of industrial processing and storage on major polyphenols and the antioxidant capacity of tropical highland blackberry (*Rubus adenotrichus*). Food Res Int 44:2243–2251
Garcia-Parra J, Gonzalez-Cebrino F, Delgado J, Lozano M, Hernandez T, Ramirez R (2011) Effect of thermal and high-pressure processing on the nutritional value and quality attributes of a nectarine puree with industrial origin during the refrigerated storage. J Food Sci 76(4):C618–C625
García-Viguera C, Zafrilla P, Romero F, Abellán P, Artés F, Tomás-Barberán FA (1999) Color stability of strawberry jam as affected by cultivar and storage temperature. J Food Sci 64(2):243–247
Georgé S, Tourniaire F, Gautier H, Goupy P, Rock E, Caris-Veyrat C (2011) Changes in the contents of carotenoids, phenolic compounds and vitamin C during technical processing and lyophilisation of red and yellow tomatoes. Food Chem 124:1603–1611
Gerard KA, Roberts JS (2004) Microwave heating of apple mash to improve juice yield and quality. LWT Food Sci Technol 37:551–557
González-Aguilar GA, Ayala-Zavala JF, De la Rosa LA, Alvarez-Parrilla E (2010) Phytochemical changes in the postharvest and minimal processing of fresh fruits and vegetables. In: De la Rosa LA, Alvarez-Parrilla E, González-Aguilar GA (eds) Fruit and vegetable phytochemicals: chemistry, nutritional value, and stability. Blackwell, Ames
Grajek W, Olejnik A (2010) The influence of food processing and home cooking on the antioxidant stability in foods. In: Smith J, Charter E (eds) Functional food product development. Blackwell, Ames

Gross J (1991) Pigments in vegetables: chlorophylls and carotenoids. Van Nostrand Reinhold, New York

Guerrero-Beltrán JA, Welti-Chanes J, Barbosa-Cánovas GV (2009) Ultraviolet-C light processing of grape, cranberry and grapefruit juices to inactivate *Saccharomyces cerevisiae*. J Food Process Eng 32:916–932

Hanes DE, Worobo RW, Orlandi PA, Burr DH, Miliotis MD, Rob MG et al (2002) Inactivation of *Cryptosporidium parvum* oocysts in fresh apple cider by UV irradiation. Appl Environ Microbiol 68:4168–4172

Howard LA, Wong AD, Perry AK, Klein BP (1999) Beta-carotene and ascorbic acid retention in fresh and processed vegetables. J Food Sci 64(5):929–936

Huang W, Bi X, Zhang X, Liao X, Hu X, Wu J (2013) Comparative study of enzymes, phenolics, carotenoids and color of apricot nectars treated by high hydrostatic pressure and high temperature short time. Innov Food Sci Emerg Technol 18:74–82

Icier F, Ilicali C (2005) The effects of concentration on electrical conductivity of orange juice concentrates during ohmic heating. Eur Food Res Technol 220:406–414

Igual M, García-Martínez E, Camacho MM, Martínez-Navarrete N (2011) Changes in flavonoid content of grapefruit juice caused by thermal treatment and storage. Innov Food Sci Emerg Technol 12:153–162

Igual M, García-Martínez E, Martín-Esparza ME, Martínez-Navarrete N (2012) Effect of processing on the drying kinetics and functional value of dried apricot. Food Res Int 47:284–290

Indrawati AC, Messagie I, Nguyen MT, Van Loey A, Hendrickx M (2004) Comparative study on pressure and temperature stability of 5-mehytltetrahydrofolic acid in model systems and in food products. J Agric Food Chem 52:485–492

Ioannou I, Hafsa I, Hamdi S, Charbonnel C, Ghoul M (2012) Review of the effects of food processing and formulation on flavonol and anthocyanin behaviour. J Food Eng 111:208–217

Jeong SM, Kim SY, Kim DR, Jo SC (2004) Effect of heat treatment on the antioxidant activity of extracts from citrus peels. J Agric Food Chem 52:3389–3393

Jiratanan T, Liu RH (2004) Antioxidant activity of processed table beets (*Beta vulgaris*, var, conditiva) and green beans (*Phaseolus vulgaris* L.). J Agric Food Chem 52(9):3659–3670

Kader A (2001) Quality assurance of harvested horticultural perishables. In: Ben-Arie R, Philosoph-Hadas S (eds) Proceedings of the 4th international conference on postharvest, 553. Acta Horticulture, Jerusalem

Kader A, Barrett DM (2005) Classification, composition of fruits, and postharvest maintenance of quality. In: Barrett DM, Somogyi L, Ramaswamy H (eds) Processing fruits: science and technology. CRC Press, Boca Raton

Kalt W (2005) Effects of production and processing factors on major fruit and vegetable antioxidants. J Food Sci 70:11–19

Kataoka I, Beppu K, Sugiyama A, Taira S (1996) Enhancement of coloration of Satohnishiki sweet cherry fruit by postharvest irradiation with ultraviolet rays. Environ Control Biol 34:313–319

Keenan DF, Brunton NP, Gormley TR, Butler F, Tiwari BK, Patras A (2010) Effect of thermal and high hydrostatic pressure processing on antioxidant activity and colour of fruit smoothies. Innov Food Sci Emerg Technol 11(4):551–556

Keenan DF, Rößle C, Gormley R, Butler F, Brunton NP (2012) Effect of high hydrostatic pressure and thermal processing on the nutritional quality and enzyme activity of fruit smoothies. LWT Food Sci Technol 45:50–57

Knorr D, Zenker M, Heinz V, Lee D (2004) Applications and potential of ultrasonics in food processing. Trends Food Sci Technol 15(5):261–266

Lado B, Yousef A (2002) Alternative food-preservation technologies: efficacy and mechanisms. Microbes Infect 4:433–440

Lamikanra O (2002) Fresh-cut fruits and vegetables: science, technology, and market. CRC Press, Boca Raton

Lee SY, Sagong HG, Ryu S, Kang DH (2012) Effect of continuous ohmic heating to inactivate *Escherichia coli* O157:H7, *Salmonella typhimurium* and *Listeria monocytogenes* in orange juice and tomato juice. J Appl Microbiol 112:723–731

Leizerson S, Shimoni E (2005) Stability and sensory shelf life of orange juice pasteurized by continuous ohmic heating. J Agric Food Chem 53(10):4012–4018

Lemmens L, Van Buggenhout S, Oey I, Van Loey A, Hendrickx M (2009) Towards a better understanding of the relationship between the beta-carotene in vitro bio-accessibility and pectin structural changes: a case study on carrots. Food Res Int 42(9):1323–1330

Leong SY, Oey I (2012) Effects of processing on anthocyanins, carotenoids and vitamin C in summer fruits and vegetables. Food Chem 133:1577–1587

Lianfu Z, Zelong L (2008) Optimization and comparison of ultrasound/microwave assisted extraction (UMAE) and ultrasonic assisted extraction (UAE) of lycopene from tomatoes. Ultrason Sonochem 15(5):731–737

Lin CH, Chang CY (2005) Textural change and antioxidant properties of broccoli under different cooking treatments. Food Chem 90:9–15

Lindley MG (1998) The impact of food processing on antioxidants in vegetable oils, fruits and vegetables. Trends Food Sci Technol 9:336–340

Lu G, Li C, Liu P, Cui H, Xia Y, Wang J (2010) Inactivation of microorganisms in apple juice using an ultraviolet silica-fiber optical device. J Photochem Photobiol B 100:167–172

Lynch M, Tauxe RV, Hedberg C (2009) The growing burden of foodborne outbreaks due to contaminated fresh produce: risks and opportunities. Epidemiol Infect 137:307–315

Magnuson BA, Jonaitis TS, Card JW (2011) A brief review of the occurrence, use, and safety of food-related nanomaterials. J Food Sci 76:R126–R133

Makris DP, Rossiter JT (2000) Heat-induced, metal-catalyzed oxidative degradation of quercetin and rutin (quercetin 3-o-rhamnosylglucoside) in aqueous model. J Agric Food Chem 48:3830–3838

Morales-de la Peña M, Salvia-Trujillo L, Rojas-Graü MA, Martín-Belloso O (2010a) Impact of high intensity pulsed electric field on antioxidant properties and quality parameters of a fruit juice-soymilk beverage in chilled storage. LWT Food Sci Technol 43:872–881

Morales-de la Peña M, Salvia-Trujillo L, Rojas-Graü MA, Martín-Belloso O (2010b) Isoflavone profile of a high intensity pulsed electric field or thermally treated fruit juice–soymilk beverage stored under refrigeration. Innov Food Sci Emerg Technol 11:604–610

Motarjemi Y, Stadler RH, Studer A, Damiano V (2009) Application of the HACCP approach for the management of processing contaminants. In: Stadler RH, Lineback DR (eds) Process-induced food toxicants: occurrence, formation, mitigation, and health risks. Wiley, Hoboken

Murakami M, Yamaguchi T, Takamura H, Matoba T (2004) Effects of thermal treatment on radical-scavenging activity of single and mixed polyphenolic compounds. Food Chem Toxicol 69:FCT7–FCT10

Niemira BA, Deschênes L (2005) Ionizing radiation processing of fruits and fruit products. In: Barrett DM, Somogyi L, Ramaswamy H (eds) Processing fruits: science and technology. CRC Press, Boca Raton

Noci F, Riener J, Walkling-Ribeiro M, Cronin D, Morgan D, Lyng J (2008) Ultraviolet irradiation and pulsed electric fields (PEF) in a hurdle strategy for the preservation of fresh apple juice. J Food Eng 85:141–146

Nuñez-Mancilla Y, Pérez-Won M, Uribe E, Vega-Gálvez A, Di Scala K (2013) Osmotic dehydration under high hydrostatic pressure: effects on antioxidant activity, total phenolics compounds, vitamin C and colour of strawberry (*Fragaria vesca*). LWT Food Sci Technol 52:151–156

Odriozola-Serrano I, Soliva-Fortuny R, Martin-Belloso O (2008a) Effect of minimal processing on bioactive compounds and color attributes of fresh-cut tomatoes. LWT Food Sci Technol 41:217–226

Odriozola-Serrano I, Soliva-Fortuny R, Martin-Belloso O (2008b) Phenolic acids, flavonoids, vitamin C and antioxidant capacity of strawberry juices processed by high-intensity pulsed electric fields or heat treatments. Eur Food Res Technol 228:239–248

Oey I, Plancken I, van der Loey A, Hendrickx M (2008) Does high pressure processing influence nutritional aspects of plant based food systems? Trends Food Sci Technol 19:300–308

Oms-Oliu G, Odriozola-Serrano I, Soliva-Fortuny R, Martín-Belloso O (2009) Effects of high-intensity pulsed electric field processing conditions on lycopene, vitamin C and antioxidant capacity of watermelon juice. Food Chem 115:1312–1319

Oms-Oliu G, Odriozola-Serrano I, Soliva-Fortuny R, Elez Martinez P, Martín-Belloso O (2012) Stability of health related compounds in plant foods through the application of non- thermal processes. Trends Food Sci Technol 23:111–123

Pap N, Pongrácz E, Jaakkola M, Tolonen T, Virtanen V, Turkki A, Horváth-Hovorka Z, Vatai G, Keiski RL (2010) The effect of pre-treatment on the anthocyanin and flavonol content of black currant juice (*Ribes nigrum* L.) in concentration by reverse osmosis. J Food Eng 98:429–436

Patil BS, Vanamalaa J, Hallmanc G (2004) Irradiation and storage influence on bioactive components and quality of early and late season, Rio Red' grapefruit (*Citrus paradise* Macf.). Postharvest Biol Technol 34:53–64

Patras A, Brunton N, Da Pieve S, Butler F, Downey G (2009a) Effect of thermal and high pressure processing on antioxidant activity and instrumental colour of tomato and carrot purees. Innov Food Sci Emerg Technol 10:16–22

Patras A, Brunton NP, Da Pieve S, Butler F (2009b) Impact of high pressure processing on total antioxidant activity, phenolic, ascorbic acid, anthocyanin content and colour of strawberry and blackberry purees. Innov Food Sci Emerg Technol 10:308–313

Périno-Issartier S, Huma Z, Abert-Vian M, Chemat F (2010) Solvent free microwave-assisted extraction of antioxidants from sea buckthorn (*Hippophae rhamnoides*) food by-products. Food Bioprocess Technol 1–9

Pilavtepe-Celik M (2013) High hydrostatic pressure (HHP) inactivation of foodborne pathogens in low-acid juices. Int J Food Sci Technol 48:673–677

Plaza L, Crespo I, de Pascual-Teresa S, de Ancos B, Sánchez-Moreno C, Muñoz M, Cano MP (2011) Impact of minimal processing on orange bioactive compounds during refrigerated storage. Food Chem 124:646–651

Prakash A, Inthajak P, Huibregtse H, Caporaso F, Foley DM (2000) Effects of low-dose gamma irradiation and conventional treatments on shelf life and quality characteristics of diced celery. J Food Sci 65(6):1070–1075

Raghavan GSV, Vigneault C, Gariépy Y, Markarian NR, Alvo P (2005) Refrigerated and controlled/modified atmosphere storage. In: Barrett DM, Somogyi L, Ramaswamy H (eds) Processing fruits: science and technology. CRC Press, Boca Raton

Ramaswamy HS, Chen CR (2002) Maximising the quality of thermally processed fruits and vegetables. In: Jongen W (ed) Fruit and vegetable processing: improving quality. Woodhead Publishing/CRC Press, Boca Raton

Ramos B, Miller FA, Brandão TRS, Teixeira P, Silva CLM (2013) Fresh fruits and vegetables-an overview on applied methodologies to improve its quality and safety. Innov Food Sci Emerg Technol. doi:10.1016/j.ifset.2013.07.002

Rattanathanalerk M, Chiewchan N, Srichumpoung W (2009) Effect of thermal processing on the quality loss of pineapple juice. J Food Eng 66:259–265

Rawson A, Koidis A, Rai DK, Tuohy M, Brunton N (2010) Influence of sous vide and water immersion processing on polyacetylene content and instrumental color of parsnip (*Pastinaca sativa*) disks. J Agric Food Chem 58(13):7740–7747

Rawson A, Patras A, Tiwari BK, Noci F, Koutchma T, Brunton N (2011a) Effect of thermal and non-thermal processing technologies on the bioactive content of exotic fruits and their products: review of recent advances. Food Res Int 44:1875–1887

Rawson A, Tiwari BK, Patras A, Brunton N, Brennan C, Cullen PJ et al (2011b) Effect of thermosonication on bioactive compounds in water-melon juice. Food Res Int 44:1168–1173

Rektor A, Pap N, Kókai Z, Szabó R, Vatai G, Békássylnár E (2004) Application of membrane filtration methods for must processing and preservation. Desalination 162:271–277

Renard CMGC, Le Quéré JM, Bauduin R, Symoneaux R, Le Bourvellec C, Baron A (2011) Modulating polyphenolic composition and organoleptic properties of apple juices by manipulating the pressing conditions. Food Chem 124:117–125

Reyes LF, Cisneros-Zevallos L (2007) Electron-beam ionizing radiation stress effects on mango fruit (*Mangifera indica* L.) antioxidant constituents before and during postharvest storage. J Agric Food Chem 55:6132–6139

Rickman JC, Barrett DM, Bruhn CM (2007a) Nutritional comparison of fresh, frozen and canned fruits and vegetables. Part 1. Vitamins B and C and phenolic compounds. J Sci Food Agric 87:930–944

Rickman JC, Bruhn CM, Barrett DM (2007b) Nutritional comparison of fresh. frozen and canned fruits and vegetables. Part 2. Vitamin A and carotenoids, vitamin E, minerals and fiber. J Sci Food Agric 87:1185–1196

Robards K (2003) Strategies for the determination of bioactive phenols in plants, fruit and vegetables. J Chromatogr A 1000(1–2):657–691

Robles-Sánchez RM, Rojas-Graüb MA, Odriozola-Serrano I, González-Aguilara GA, Martín-Belloso O (2009) Effect of minimal processing on bioactive compounds and antioxidant activity of fresh-cut 'Kent' mango (*Mangifera indica* L.). Postharvest Biol Technol 51:384–390

Ropkins K, Beck AJ (2003) Using HACCP to control organic chemical hazards in food wholesale, distribution, storage and retail. Trends Food Sci Technol 14:374–389

Ropkins K, Ferguson A, Beck AJ (2003) Development of Hazard Analysis by Critical Control Points (HACCP) procedures to control organic chemical hazards in the agricultural production of raw food commodities. Crit Rev Food Sci Nutr 43(3):287–316

Ruiz-Cruz S, Arvizu-Medrano S (2010) Quality loss of fruits and vegetables induced by microbial growth. In: De la Rosa LA, Alvarez-Parrilla E, González-Aguilar GA (eds) Fruit and vegetable phytochemicals: chemistry, nutritional value, and stability. Blackwell, Ames

Sajilata MG, Singhal RS (2006) Effect of irradiation and storage on the antioxidative activity of cashew nuts. Radiat Phys Chem 75:297–300

Saldana MDA, Gamarra FMC, Siloto RMP (2010) Emerging technologies used for the extraction of phytochemicals from fruits, vegetables, and other natural sources. In: De la Rosa LA, Alvarez-Parrilla E, González-Aguilar GA (eds) Fruit and vegetable phytochemicals: chemistry, nutritional value, and stability. Blackwell, Ames

Sanchez-Moreno C, Plaza L, De Ancos B, Cano MP (2003) Vitamin C, provitamin A carotenoids, and other carotenoids in high pressurized orange juice during refrigerated storage. J Agric Food Chem 51:647–653

Saxena A, Bawa AS, Raju PS (2008) Use of modified atmosphere packaging to extend shelf-life of minimally processed jackfruit (*Artocarpus heterophyllus* L.) bulbs. J Food Eng 87(4):455–466

Skrede G, Wrolstad RE, Durst RW (2000) Changes in anthocyanins and polyphenolics during juice processing of highbush blueberries (*Vaccinium corymbosum* L.). J Food Sci 65:357–364

Song HP, Kim DH, Jo C, Lee CH, Kim KS, Byun MW (2006) Effect of gamma irradiation on the microbiological quality and antioxidant activity of fresh vegetable juice. Food Microbiol 23:372–378

Srinivas K, King JW, Monrad JK, Howard LR, Zhang D (2011) Pressurized solvent extraction of flavonoids from grape pomace utilizing organic acid additives. Italian J Food Sci 23(1):90–105

Strawn LK, Schneider KR, Danyluk MD (2011) Microbial safety of tropical fruits. Crit Rev Food Sci Nutr 51:132–145

Sumnu G, Sahin S (2005) Recent developments in microwave heating. In: Sun DW (ed) Emerging technologies for food processing. Elsevier, San Diego

Szczesniak AS (1998) Effect of storage on texture. In: Taub IA, Singh RP (eds) Food storage stability. CRC Press, Boca Raton

Tait J, Bruce A (2001) Globalization and transboundary risk regulation: pesticides and genetically modified crops. Health Risk Soc 3:99–112

Takahama U (1986) Spectrophotometric study on the oxidation of rutin by horseradish peroxidase and characteristics of the oxidized products. BBA Gen Sub 882(3):445–451

Tiwari U, Cummins E (2013) Factors influencing levels of phytochemicals in selected fruit and vegetables during pre- and post-harvest food processing operations. Food Res Int 50:497–506

Tiwari BK, O'Donnell CP, Cullen PJ (2009a) Effect of nonthermal processing technologies on the anthocyanin content of fruit juices. Trends Food Sci Technol 20:137–145

Tiwari BK, O'Donnell CP, Muthukumarappan K, Culllen PJ (2009b) Ascorbic acid degradation kinetics of sonicated orange juice during storage and comparison with thermally pasteurized juice. LWT Food Sci Technol 42:700–704

Tiwari BK, O'Donnell CP, Patras A, Brunton N, Culllen PJ (2009c) Stability of anthocyanins and ascorbic acid in sonicated strawberry juice during storage. Eur Food Res Technol 228: 717–724

Turkmen N, Sari F, Velioglu YS (2005) The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. Food Chem 93:713–718

Uckoo RM, Jayaprakasha GK, Somerville JA, Balasubramaniam VM, Pinarte M, Patil BS (2013) High pressure processing controls microbial growth and minimally alters the levels of health promoting compounds in grapefruit (*Citrus paradisi* Macfad) juice. Innov Food Sci Emerg Technol 18:7–14

Van Boekel M, Fogliano V, Pellegrini N, Stanton C, Scholz G, Lalljie S, Somoza V, Knorr D, Jasti PR, Eisenbrand G (2010) A review on the beneficial aspects of food processing. Mol Nutr Food Res 54:1215–1247

Van Boxstael S, Habib I, Jacxsens L, De Vocht M, Baert L, Van De Perre E, Rajkovic A, Lopez-Galvez F, Sampers I, Spanoghe P, De Meulenaer B, Uyttendaele M (2013) Food safety issues in fresh produce: bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. Food Control 32:190–197

Van Der Sluis AA, Dekker M, Skrede G, Jongen WM (2002) Activity and concentration of polyphenolic antioxidants in apple juice. 1- Effect of existing production methods. J Agric Food Chem 50:7211–7219

Varma S, Karwe MV, Lee TC (2010) Effect of high hydrostatic pressure processing on lycopene isomers. Int J Food Eng 6:1–20

Vervoort L, Van der Plancken I, Grauwet T, Timmermans RAH, Mastwijk HC, Matser AM, Hendrickx ME, Loey AV (2011) Comparing equivalent thermal, high pressure and pulsed electric field processes for mild pasteurization of orange juice. Part II. Impact on specific chemical and biochemical quality parameters. Innov Food Sci Emerg Technol 12:466–477

Vikram VB, Ramesh MN, Prapulla SG (2005) Thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. J Food Eng 69:31–40

Villavicencio ALCH, Mancini-Filho J, Delincee H, Greiner R (2000) Effect of irradiation on antinutrients (total phenolics, tannins and phytate) in Brazilian beans. Radiat Phys Chem 57: 289–293

Vinha AF, Alves RC, Barreira SVP, Castro A, Costa ASG, Oliveira MBPP (2013) Effect of peel and seed removal on the nutritional value and antioxidant activity of tomato (*Lycopersicon esculentum* L.) fruits. LWT Food Sci Technol. doi:10.1016/j.lwt.2013.07.016

Volden J, Bengtsson GB, Wicklund T (2009) Glucosinolates, L-ascorbic acid, total phenols, anthocyanins, antioxidant capacities and color in cauliflower (*Brassica oleracea* L. ssp. botrytis); effects of long-term freezer storage. Food Chem 112(4):967–976

Wachtel-Galor S, Wong KW, Benzie IFF (2008) The effect of cooking on Brassica vegetables. Food Chem 110:706–710

Wicklung T, Rosenfeld HJ, Martinsen BK, Sundfor MW et al (2005) Antioxidant capacity and colour of strawberry jam as influenced by cultivar and storage conditions. LWT Food Sci Technol 38:387–391

Wong PYY, Kitts DD (2001) Factors influencing ultraviolet and electron beam irradiation-induced free radical damage of ascorbic acid. Food Chem 74:75–84

Yildiz H, Bozkurt H, Icier F (2009) Ohmic and conventional heating of pomegranate juice: effects on rheology, color, and total phenolics. Food Sci Technol Int 15:503–511

Zafrilla P, Ferreres F, Tomás-Barberán FA (2001) Effect of processing and storage on the antioxidant ellagic acid derivatives and flavonoids of red raspberry (*Rubus idaeus*) jams. J Agric Food Chem 49(8):3651–3655

Zainol MM, Abdul-Hamid A, Bakar FA, Dek SP (2009) Effect of different drying methods on the degradation of selected flavonoids in *Centella asiatica*. Int Food Res J 4:531–537

Zenker M, Heinz V, Knorr D (2003) Application of ultrasound assisted thermal processing for preservation and quality retention of liquid foods. J Food Prot 66:1642–1649

Zepka LQ, Mercadante AZ (2009) Degradation compounds of carotenoids formed during heating of a simulated cashew apple juice. Food Chem 117:28–34

Zhang M, Hettiarachchy NS, Horax R, Chen P, Over KF (2009) Effect of maturity stages and drying methods on the retention of selected nutrients and phytochemicals in bittermelon (*Momordica charantia*) leaf. J Food Sci 74(6):C441–C446

Zill EH, Abert-Vian M, Elmaataoui M, Chemat F (2011) A novel idea in food extraction field: study of vacuum microwave hydrodiffusion technique for byproducts extraction. J Food Eng 105(2):351–360