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Nonthermal Technologies for Fruit and Vegetable Juices and Beverages: Overview and Advances

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Abstract: In recent years, there has been a growing interest in the design of novel nonthermal processing systems that minimally modify sensory, nutritional, and functional properties of fruit and vegetable juices and beverages. The benefits of nonthermal treatments are strongly dependent on the food matrix. Thus, an understanding of the effects that these technologies exert on the properties of juices and beverages is important to design and optimize technological parameters to produce value-added products. This review covers research on nonthermal electrical treatments, high pressure processing, ultrasound, radiation processing, inert gas treatments, cold plasma, and membrane processing. Advances towards optimization of processing conditions, and combined technologies approaches have been also extensively reviewed. This information could be useful to: (1) manage processing systems and optimize resources; (2) preserve nutritional value and organoleptic properties, and (3) provide processing conditions for validation of these technologies at the industrial scale.

Keywords: biopreservation, hurdle technology, juices and beverages, nonthermal processing

Introduction

A diet rich in fruits and vegetables can have a positive impact on health and wellbeing of humans (Gironés-Vilaplana and others 2016), due to some bioactive compounds (tocopherols, carotenoids, polyphenols, phenolics, and anthocyanins) (Kongkachuichai and others 2015), vitamins, minerals, and fibers (Liu 2013).

For a 2000-kcal diet, the 2010 Dietary Guidelines for Americans recommend 9 servings of fruits and vegetables per day, 4 servings of fruits and 5 servings of vegetables (Liu 2013). The European Union supports the WHO recommendation for at least 400 g/d of fresh fruits and vegetables (Tennant and others 2014).

Despite these guidelines, consumption of vegetables and fruit remains below the recommended levels in many countries and a substantial burden of disease globally is attributable to low consumption (Mytton and others 2014). In Europe, consumption is at 220 g per person per day for adults. In the United Sates, only 6% to 8% of individuals achieve their recommended daily target, with the average American consuming only 1.8 cups of fruits and vegetables per day (Rekhy and McConchie 2014).

The strategies to increase fruit and vegetable consumption are a key focus for population health (Mytton and others 2014). Therefore, promoting fruit and vegetable consumption is a key objective of food and nutrition policy interventions conducted around the world by government and nongovernment stakeholders (Rekhy and McConchie 2014). Fruit and vegetable juices, juice blends, smoothies, fermented and enriched beverages are an increasingly popular way of consuming fruit and fresh-like vegetables and may contribute to a healthy diet and healthy life (Wootton-Beard and Ryan 2011; Corbo and others 2014; Marsh and others 2014; Ramachandran and Nagarajan 2014; Hurtado and others 2015).

Vegetable and fruit juices are traditionally preserved by thermal processing. However, recent consumer demands for safe and minimally processed foods with high-quality attributes have encouraged food industry and scientific researchers to design alternative nonthermal technologies to produce foods with a minimum of changes induced by the technologies themselves (Bhat and Stamminger 2015a; Jiménez-Sánchez and others 2017a). Although nonthermal treatment seems less detrimental than the thermal ones, the effects are strongly dependent on the food matrix (Alves Filho and others 2016). Therefore, the main motivation for food processors is to select the most appropriate nonthermal technology along with validated processing conditions to retain nutritive constituents and color and flavor attributes (Koutchma and others 2016).

Some articles addressed fruit juice processing (Echavarría and others 2011; Chen and others 2012; Evrendilek and others 2012; Abdullah and Chin 2014; Aneja and others 2014; Zinoviadou and others 2015; Koutchma and others 2016; Shah and others, 2016; Anaya-Esparza and others 2017; Jiménez-Sánchez and others 2017a,b), but to the best of our knowledge no report gives a comprehensive picture of all available nonthermal technologies, as well as on the approaches to improve their effectiveness in different kind of products including fruit and vegetable juices, juice blends, smoothies, enriched and fermented beverages. This review covers researches on this topic in the last 5 to 10 y, with a particular emphasis on products derived from different botanical sources. The technologies presented include nonthermal electrical treatments,

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Table 1–How alternative approaches work in juices and beverages: an overview.

Kind of approach	How it works
Electrical	The antimicrobial activity relies upon the use of two electrodes which generate pulsed electric fields, high voltage currents or radio-frequencies.
Pressure	Products are placed into a high-pressure vessel in their flexible packages and submitted to high pressure by water (high hydrostatic pressure). For homogenization, juices and beverages are forced to pass through a small valve and divided into nanobubbles (micronization; high pressure homogenization).
Ultrasound	Products are treated through sonic waves generated by probes or in a bath. The antimicrobial activity is the result of cavitation.
Radiation	Products are treated by radiation at different wavelengths (UV, γ-radiation, electron beams). The process can be either continuous or discontinuous (pulsed light).
	A particular application is the use of nanoparticles of titanium dioxide, which produce strong oxidizing agents when irradiated by UV.
Gas	Some applications are alternative ways to high hydrostatic pressure, as the increase of pressure is generated by a gas (nitrogen or helium in pressure change technology [PCT] or supercritical CO_2 in dense phase carbon dioxide [DPCD]).
	Ozonation relies on the use of O_3 as an antimicrobial agent; it is spread into the media through a sparger.
Cold plasma	Cold plasma is generated by using electricity and a carrier gas. The result is electrical discharges and subsequent ionization of atmospheric air.
Membrane	Sterilization relies on the physical separation of microorganisms through membranes (micro- or nanofiltration); the treatments differ for the pores of the membranes. In this class, we can also find reverse- and forward osmosis; the main aim of this technology is juice concentration, but a secondary goal is the antimicrobial effect.

high pressure processing, ultrasound, radiation processing, inert gas treatments, cold plasma, and membrane processing. Table 1 shows how each approach works in juices and beverages.

Nonthermal/Electrical Processing

Pulsed electric fields

Pulsed eletric fields (PEFs) is a technology that has been extensively investigated for its applications in food processing (Rawson and others 2011a). During the last years, transition from lab- and pilot-scale equipment to industrial-scale equipment took place, and the first PEF processed fruit juices and smoothies are on the market in different countries (The Netherlands, Germany, the United Kingdom, and Austria) (Buckow and others 2013; Timmermans and others 2016). For example, the first commercial application of PEF started in 2009 (Toepfl 2012) and Timmermans and others (2016) reported the presence of PEF-treated juices on the shelves of The Netherlands, United Kingdom, and Germany. An industrial application of PEF was reported for the treatment of wastewater in the United States by Li and Farid (2016).

PEF is a valid technology for the production of safe beverage products with high added value (Rawson and others 2011a). The application of PEF pulses leads to the permeabilization of biological membranes. The plasma membranes of cells become permeable to small molecules after being exposed to an electric field; the permeation induces swelling and the eventual rupture of the cell membrane, reducing or eliminating the microbial load (Jiménez-Sánchez and others 2017a). Table 2 provides a comprehensive summary of the outcomes of recent studies on this technology.

Bansal and others (2015) reported a 5.1 log reduction of *Zygosaccharomyces bailii* (MTCC 257) in amla juice, as well as a 63% and 88.9% retention of ascorbic acid and antioxidant capacity. Kathiravan and others (2014) reduced the native microflora in coconut water-nannari blended beverage by 3 log CFU/mL; in addition, the shelf life of PEF-treated samples was 120 d at 27 to 30 °C. Mosqueda-Melgar and others (2012) reported the complete inactivation of naturally occurring microorganisms of pear juice, without changes in the sensory attributes. PEF was also tested in juice blends (Morales-de la Peña and others 2010; Salvia-Trujillo and others 2011) and in grape wines (González-Arenzana and others 2015).

In comparison to traditional pasteurization, PEF was found to keep the content and structures of sensitive bioactive compounds, like ascorbic acid betacyanins in twistspine pricklypear juice (Moussa-Ayoub and others 2011), ascorbic acid and flavor compounds in longan juice (Zhang and others 2010), carotenoids in orange juice (Plaza and others 2011), ascorbic acid in a juice-blend mixed with soymilk (Rodríguez-Roque and others 2014). In addition, PEF exerted a positive effect on 15-*cis*-lycopene in tomato juice (Vallverdú-Queralt and others 2013).

The use of PEF for enzymes inactivation has been proposed by many authors. Quintão and others (2013) reported up to 93% of the initial peroxidase activity (POD) in carrot juice. In a juice-blend mixed with whole or skim milk, PEF reduced by 26.92% and 20.93% polygalacturonase (PG; Salvia-Trujillo and others 2011). In a juice-blend mixed with soymilk, POD and lypoxigenase (LOX) were inactivated by PEF by 17.5% to 29% and 34% to 39%, respectively (Morales-de la Peña and others 2010).

Some negative effects were also reported, like the decrease of ascorbic acid content in apple juice (Bi and others 2013), or a marginal inactivation of pectin methyl esterase (PME; 14% inactivation) in a carrot/orange juice blend (Caminiti and others 2012).

Although the application of PEF at relatively lower temperatures to inactivate foodborne and food spoilage bacteria, and enzymes has been well described in the literature, a better understanding and accurate prediction of inactivation levels are necessary to achieve enzymatically stable products without overprocessing (Ağçam and others 2014). However, more studies are required to understand PEF resistance of Gram-positive and Gram-negative bacteria in relation to the thickness of cell membrane and cell wall (Huang and others 2014).

Radio frequency electric fields

Radio frequency electric fields (RFEF), also known as electric currents that oscillate at radio frequencies in the range of about 3 Hz to 300 GHz, was proposed as a nonthermal pasteurization method for the inactivation of bacteria in juices. RFEF process is similar to PEF with a single difference: in PEF the high voltage is applied in pulses using a pulse generator, whereas in RFEF processing, the voltage is applied continuously using an alternating current generator (Jiménez-Sánchez and others 2017a). The knowledge of the mode of action of RFEF is limited (Ukuku and others 2012); however, some authors suggested that the inactivation of bacteria is the result of the disruption of the bacterial surface structure, leading leakage of intracellular biological active compounds (Jiménez-Sánchez and others 2017a). Ukuku and Geveke (2010) reported that RFEF reduced *Escherichia coli* K-12 in apple juice from 8 log CFU/mL to 4.9 log CFU/mL; the

Table 2–Electrical processing.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
		Pulsed electric fields		
Amla	Juice	1 Hz; 26 kV/cm; 1 μs; 500 μs; <41°C	5.1 log reduction of *Z. bailii* (MTCC 257). 63% and 88.9% retention of ascorbic acid and antioxidant capacity.	Bansal and others (2015)
Apple	Juice	16 Hz; 0 to 35 kV/cm; 0.2 and 2 μs; 75 μs; <42 °C	The content of ascorbic acid decreased significantly during PEF treatment, the highest loss was 36.6% at 30 kV/cm and 2 μs-pulse rise time.	Bi and others (2013)
Apple	Cider	1600 Hz; 5 to 23 kV/cm; 2.5 μs; 150 μs; 48 °C	PEF-treated cider maintained good microbial quality and sensory attributes during 4 wk of refrigerated storage.	Azhuvalappil and others (2010)
Apple, cranberry	Juice blend	18 Hz; 34 kV/cm; 1 μs; 93 μs; 20 °C	4 log reduction of *Escherichia coli* (K 12 DSM 1607) and *P. fermentans* (DSM 70090).	Palgan and others (2011)
Apple, mango, orange, pineapple	Smoothie	1 kHz; 25 kV/cm; 4 to 32 μs; <35 °C	2 to 3 log reduction of *L. innocua* (NCTC 11288).	Palgan and others (2012)
Apricot	Nectar	125 to 400 Hz; 24 kV/cm; 66 to 210 μs; <23 °C	No effect on the sensory scores.	Evrendilek (2016)
Blueberry	Juice	30 kV/cm; 54 μs and 20 to 35 kV/cm; 27 to 82 μs	*E. coli* reduced by 5.12 log CFU/mL. Ascorbic acid was reduced by 14.78%, whereas anthocyanin content was reduced by 3.64%. Good retention of color and nutrients.	Chen and others (2014)
Broccoli	Juice	15 to 35 kV/cm; 500 to 2000 μs; <35 °C	No effect on myrosinase, because PEF samples contained a lower concentration of glucosinolates.	Frandsen and others (2014)
Carrot	Juice	200 Hz; 20 to 35 kV/cm; 6 μs; 300 to 2000 μs; <40 °C	POD reduced by 93% at 35 kV/cm for 1500 μs.	Quintão-Teixeira and others (2013)
Carrot, orange	Juice blend	18 Hz; 24 kV/cm; 1μs; 89 μs; <49 °C	Partial inactivation of PME (14%).	Caminiti and others (2012)
Coconut, nannari	Blended beverage	100 Hz; 31.2 kV/cm; 20 μs; <35 °C	3 log reduction of native microflora. Shefl life of 120 d at 27 to 30 °C.	Kathiravan and others (2014)
Date	Juice	100 Hz; 35 kV/cm; 4 μs; 1,000 μs; <35 °C	Lower HMF concentration than pasteurized samples. Beneficial effect on turbidity, soluble solids and pH. The content of total phenols increased after treatment compared to untreated juice.	Mtaoua and others (2017)
Grape	Juice	120 Hz; 12–24 kV/cm; 3 μs; 30 to 180 μs; <38.2 °C	Lower resistance of *S. cerevisiae* (CICC 1374) compared to *E. coli* DH5α and *S. aureus* (CICC 21648). Possible effects of the higher values of transmembrane potential.	Huang and others (2014)
Grape	Wine	60 to 95 kV/cm; 40 min; <22°C	Inactivation of 0.64 to 4.94 log CFU/mL in 25 species of yeast, lactic acid bacteria and acetic acid bacteria associated with wines.	González-Arenzana and others (2015)
Grapefruit	Juice	28 kV/cm; 2 μs; 100 μs; <22 °C	Color change to yellow.	Hartyáni and others (2011)
Kiwifruit, orange, pineapple	Juice-blend mixed with soymilk	200 Hz; 35 kV/cm; 4 μs; 800 and 1400 μs; <32 °C	PEF processing for 800 μs ensured the microbial stability for 31 d; however, a longer microbial shelf life (56 d) was achieved by increasing the treatment time to 1400 μs. POD and LOX of PEF treated beverages were inactivated by 17.5% to 29% and 34% to 39%, respectively. Good preservation of nutritional values and fresh-like characteristics.	Morales-de la Peña and others (2010)
Kiwifruit, mango, orange, pineapple	Juice-blend mixed with soymilk	200 Hz; 35 kV;/cm; 4-μs; 1800 μs; <35 °C	The bioaccessibility of ascorbic acid was not modified.	Rodríguez-Roque and others (2014)
Kiwifruit, mango, orange, pineapple	Juice-blend mixed with whole or skim milk	200 Hz; 35 kV/cm; 4 μs; 1800 μs; <40 °C	PEF ensured the microbial stability of the beverages for 56 d-refrigerated storage. Polygalacturonase (PG) reduced by 26.92% and 20.93% in the whole and skim milk-added beverages.	Salvia-Trujillo and others (2011)
Longan	Juice	10 Hz; 32 kV/cm; 3 μs; 90 s; <40 °C	High retention of ascorbic acid and flavor compounds.	Zhang and others (2010)
Mango	Juice	200 Hz; 35 kV/cm; 4 μs; 1500 μs; <40 °C	PEF treatment did not negatively influence the antioxidant activity.	Odriozola-Serrano and others (2016)

(*Continued*)

Table 2–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
Mango, papaya	Juice blend sweetened with *Stevia rebaudiana*	32 and 256 kJ/kg; <35 °C	High retention of the ascorbic acid content (80% to 83%). Total carotenoids were significantly higher than untreated sample; reduction of carotenoids at 256 kJ/kg, total carotenoid diminished significantly. Phenolic concentration after PEF treatment at 256 kJ/kg was significantly higher.	Carbonell-Capella and others (2016)
Mango	Nectar	70 to 120 Hz; 38 kV/cm; 15 to 24 μs; <35 °C	The maximum inactivation of native microflora (4.1 log CFU/mL), retention of carotene content (2100 μg/100mL) and overall acceptability (8.3) scores were obtained for 120 Hz/24 μs PEF-treatment.	Kumar and others (2015)
Mandarin	Juice	28 kV/cm; 2 μs; 100 μs; <22 °C	Color change to yellow.	Hartyáni and others (2011)
Orange	Juice	800 Hz; 35 kV/cm; 4 μs; 750 μs; <50°C	No effect on carotenoids.	Plaza and others (2011)
Passion fruit	Juice	85 to 100 Hz; 38.1 kV/cm; 19 to 24 μs; <40 °C	The highest inactivation (total plate count 4.079 log CFU/mL, coliforms 4.1 log CFU/mL and yeast and moulds 3.95 log CFU/mL) was observed after treating juice 24 μs pulse width, at 100 Hz frequency.	Kathiravan and others (2013)
Peach	Juice	55 Hz; 36 kV/cm; 21 μs; 25 °C	Ascorbic acid retention increased more than 10%.	Meneses and others (2011)
Peach	Nectar	3 μs; 66 to 210 μs; <40 °C	Loss of aroma active compounds.	Evrendilek and others (2016)
Pear	Juice	215 Hz; 35 kV/cm; 1600 μs; <40 °C	Complete inactivation of naturally occurring microorganisms. No significant changes of the sensory attributes.	Mosqueda-Melgar and others (2012)
Pineapple	Juice	10 to 30 kV/cm; 5 min; 25 to 26 °C	30 kV/cm treatment exerted the best effect on the overall juice characteristics.	Dastgheib and others (2014)
Prickly pear	Juice	25 and 50 Hz; 27 to 36 kV/cm; 11 to 15 μs; 25 °C	The highest reduction of *S. cerevisiae* (ATCC 26109) (5.3 log CFU/mL) was achieved at 15 μs–50 Hz–36 kV/cm	García- García and others (2015)
Sour cherry	Juice	0 to 30 kV/cm; 3 μs; 131 μs or 17 kV/cm; 3 μs; 210 μs	The inactivation of *E. coli* O157:H7 (EDL 931 04054), *S. aureus* (95047), *L. monocytogenes* (Type I 04077), *Erwinia carotovora*, *Ps. syringae* subs. *syringae*, *Botrytis cinerea* and *Penicillium expansum* significantly increased by increasing electric field strength and treatment time.	Altuntas and others (2010)
Strawberry	Juice	50 to 250 Hz; 35 kV/cm; 1 to 7 μs; 1000 to 2000 μs; <40 °C	PPO residual activity reduced by 2.5% (frequency> 229 Hz and pulse, 3.23 to 4.23 μs for 2000 μs).	Aguiló-Aguayo and others (2010b)
Sugarcane	Juice added with lemon and ginger	10 to 30 and 30 to 50 kV cm^{-1}; 110 and 240 s	Control of yeast growth for 7 d.	Kayalvizhi and others (2016)
Tomato	Juice	100 Hz; 35 kV/cm; 4 μs; 1500 μs; <40 °C	An enhancement of 63% to 65% in 15-*cis*-lycopene content.	Vallverdú-Queralt and others (2013)
Twistspine pricklypear	Juice	35 kV/cm	Good preservation of antioxidant activity.	Moussa-Ayoub and others (2011)
Watermelon	Juice	188 Hz; 35 kV/cm; 1727 μs; <35 °C	Brighter red color. Viscosity was enhanced.	Aguiló-Aguayo and others (2010a)
		Radio-frequency electric fields		
Apple	Juice	20 kHz; 15 kV/cm; 170 μs; 40 °C	Reduction of *E. coli* K-12 <3 log CFU/mL.	Ukuku and Geveke (2010)
		High-voltage electric discharges		
Grape	Wine	0.33 Hz; 40 kV; <34.4 °C	No effect on *Pd. parvulus* (CRBO 2.6), *Br. bruxellensis* (CB 28), and *O. oeni* (CRBO 9304 and CRBO 0608). Decrease of phenolic content. Increase of the glucose-fructose and residual reducing sugar concentrations.	Delsart and others (2015)
Mango, papaya	Juice blend sweetened with *Stevia rebaudiana*	108 Hz; 40 kV	Effect on the she stability of steviol glycosides (stevioside, rebaudioside A, rebaoudioside F rebaoudioside C).	Buniowska and others (2016)

surviving population was below the detection limit after 24 h-storage at 5 and 23 °C.

High-voltage electrical discharges

High-voltage electrical discarges (HVEDs) create electric arcs by the application of electric fields between two points or flat electrodes. The intensity of the electric fields is higher than that used in PEF and causes the fragmentation of solid particles. The energy is converted into mechanical (shock wave), chemical energy (active species in the arc channel), or light. As a result, there is less energy converted into heat (Delsart and others 2015). Delsart and others (2015) studied the effect of HVED on some quality parameters and the inactivation of *Oenococcus oeni*, *Pediococcus parvulus*, and *Brettanomyces bruxellensis* in red wine. Recently, Buniowska and others (2016) explored the possibily of using HVED as a tool to preserve the content of steviol glycosides (stevioside, rebaudioside A, rebaoudioside F rebaoudioside C) in a mango/papaya juice blend sweetened with *Stevia rebaudiana*.

High-Pressure Processing

High-pressure treatments include hydrodynamic treatment (high-pressure homogenization, HPH) and hydrostatic treatments (high hydrostatic pressure, HHP). HPH (70 to 200 MPa) applies pressures in continuous to fluid products (Suárez-Jacobo and others 2014), whereas HHP is applied in batch systems to both solid and fluid products already packaged, using a pressure between 150 to 900 MPa (Betoret and others 2015). Recently, Ultra-high-pressure homogenization (UHPH; 200 to 400 MPa; Suárez-Jacobo and others 2014) and pulsed-high hydrostatic pressure (p-HHP; combination of pressure, temperature, and pulses) have also been applied to preserve fruit and vegetable juices. A summary of the most recent studies is in Table 3.

High hydrostatic pressure

Probably the most developed and most widely implanted technology at the industrial level is HHP (Bello and others 2014). This technology exerts limited effects on small molecules such as volatile compounds, pigments, vitamins, and antioxidant compounds, owing to its limited impacts on the covalent bonds and its low processing temperature (Chen and others 2015a).

HHP has proved to be an effective technology to prolong the shelf life of many juices, including apple (Juarez-Enriquez and others 2015), orange (Wang and others 2012a), asparagus (Chen and others 2015c), pomegranate (Chen and others 2013), strawberry (Cao and others 2012), and mango (Hiremath and Ramaswamy 2012). The response of microorganisms to high pressures varies according to the following factors: molds and yeasts are the most sensitive microorganisms; Gram-negative bacteria have medium sensitivity, whereas Gram-positive bacteria are the most resistant and their spores require very high pressures to be inactivated (Bello and others 2014).

Overall, the inactivation of spoilage enzymes in juices often leads to difficulties as the sensitivities of enzymes are unpredictable and rely on the kind of product (Chakraborty and others 2014). In addition, there are some evidences on a possible enhancement of enzyme activity (Chakraborty and others 2014), as reported by Gao and others (2015) for POD in pummelo juice, and Huang and others (2013) for polyphenol oxidase (PPO) and POD in apricot nectar. However, under proper conditions, HHP treatment can result in the inactivation of enzymes, as recently confirmed by Juarez-Enriquez and others (2015) for PME in apple juice, and Rao and others (2014) for PPO and PME in peach juice, respectively. Under the high-pressure environment, the mechanism of enzyme inactivation can be hypothesized similar to protein denaturation. The application of pressure might induce reversible or irreversible and partial or complete unfolding of the native structure of the enzyme (Chakraborty and others 2014).

HHP treatments ensure high-quality levels in terms of nutrient and vitamin preservation. For example, pressurization applied on asparagus juice resulted in a significantly higher retention of ascorbic acid, rutin, total phenolics contents, and total antioxidant activity than thermal treatment (Chen and others 2015c). Rodríguez-Roque and others (2014) found that the bioaccessibility of ascorbic acid was not modified by HHP treatment using a juice-blend mixed with milk or soymilk. HHP preserved fructooligosaccharides (FOS) in cranberry juice (Gomes and others 2017). Recently, Hao and others (2016) highlighted the possible application of HHP process as a valuable tool to reduce the content of patulin, a mycotoxin of concern in beverages, in different juice blends.

Some negative effects were also reported, like the decrease of total phenolics, total anthocyanins, tartaric esters, flavonols and tannins in wine (Tao and others 2012), ascorbic acid, anthocyanins, total phenols and antioxidant in a strawberry juice (Cao and others 2012), as well as ester compounds in a strawberry nectar (Xu and Liao 2011).

At this stage of development of HHP technology, the evaluation of the influence of process variables on the stability of bioactive compounds as well as on the antioxidant capacity and physicochemical parameters of products is a key factor in defining treatment conditions to avoid the loss of these important properties of foods and to obtain a food beverage with high benefits for the health of the consumer (Barba and others 2013). However, it would be interesting to determine how this technology can modulate the bioavailability of minerals. Applying emerging technologies (that is, high-pressure techniques) as an alternative to traditional heat processing would be more valuable if nutritional quality is considered not only as a stability issue but also as a bioavailability concern, because the bioavailability of nutrients can be increased by HHP (Cilla and others 2011). Finally, to fulfil the economic feasibility of the HHP process, a pressure within 300 MPa should be applied to reduce capital equipment cost, processing time to 5 min without affecting the inactivation of both pathogenic and spoilage microbiota (Scolari and others 2015).

Pulsed-high hydrostatic pressure

Most of HHP studies report impact of static pressurization and few works focus on different modes of pressurization, which might be due to the fact that pulsed pressure treatments are not considered feasible for application due to the high stress on the pressure vessels (Kaushik and others 2016). In addition, Kaushik and others (2016) stated that pulsation might enhance the activity of browning enzymes like PPO and POD.

High-pressure homogenization

Over the last years, the effect of HPH (pressures in the range 20–150 MPa) on microbiological quality of fruit and vegetable juices has been widely investigated in a number of studies (Patrignani and others 2010; Carreño and others 2011; Belloch and others 2012; Bevilacqua and others 2012a). Because of the effect on food constituents (proteins, fat, and polysaccharides) with consequent modification of their functional properties and susceptibility to enzymatic attack, HPH has been also proposed to modify food

Table 3–High pressure.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
		High hydrostatic pressure		
Apple	Juice	430 MPa; 7 min	Total inactivation of PME and indigenous microbiota. No significant changes in physicochemical properties, nutritive value or sensory attributes.	Juarez-Enriquez and others (2015)
Apple, banana, blackberry, gooseberry, grape, lime, orange, strawberry	Smoothie	350 MPa; 5 min; <10 °C	The microbial quality of smoothies was adequately controlled by the treatment. Low efficacy in inactivating the oxidative (PPO and POD) and hydrolytic (PME) enzymes. Possible oxidation and clarification, which might lead to undesirable sensory and nutritional changes.	Hurtado and others (2017)
Apple, banana, orange, strawberry	Smoothie	450 MPa; 5 min; or 600 MPa; 10 min; 20 °C	Samples processed at 450 MPa/5 min were similar to unprocessed controls and appeared to retain fresh-like characteristics. No complete inactivation of PPO.	Keenan and others (2012a)
Apple, bilberry, blackberry, raspberry, red currant, grape, orange, strawberry	Smoothie	100 to 300 MPa; 5 min; −5 to 45 °C	Microbial inactivation was proportional to the pressure applied. At the highest pressure level, the lactic acid population was reduced more effectively at 45 °C (6 log reduction) than at −5 °C (3.3 log reduction).	Zacconi and others (2015)
Apple, beetroot, carrot, ginger, lemon	Juice blend	400 to 600 MPa; 0 to 300 s; 11 °C	The largest decrease in patulin was 45 ppb (0.29 μM) using 600 MPa for 300 s.	Hao and others (2016)
Apple, celery, cucumber, kale, lemon, parsley, romaine, spinach	Juice blend	400 to 600 MPa; 0 to 300 s; 11 °C	The highest level of patulin degradation (60 ppb, 0.39 μM) was recorded for treatments at 600 MPa for 300 s.	Hao and others (2016)
Apple, mint, pineapple	Juice blend	400 to 600 MPa; 0 to 300 s; 11 °C	The largest decrease of patulin in juice blend was 48 ppb (0.31μM) when treated at 600 MPa for 300 s.	Hao and others (2016)
Apple, spinach	Juice blend	400 to 600 MPa; 0 to 300 s; 11 °C	The highest level of patulin degradation (43 ppb, 0.28 μM) was recorded for treatments at 600 MPa for 300 s.	Hao and others (2016)
Apricot	Nectar	300 to 500 MPa; 5 to 20 min; <40 °C	PPO and POD were significantly activated and the activity of PME was not changed by HHP treatments. Increase of total and individual phenolics. Good overall quality.	Huang and others (2013)
Ashitaba	Juice	550 MPa; 90 s	Yeasts and molds, coliform bacteria, and *Pseudomonas* were inactivated by HHP to levels below the detection limit, but *B. cereus* survived and increased during the refrigerated storage.	Chai and others (2014)
Asparagus	Juice	200 to 600 MPa; 10 and 20 min; ~25 °C	HHP at 400 and 600 MPa ensured the complete decontamination of juice. HHP treatments retained significantly higher ascorbic acid, rutin, total phenolics contents, and total antioxidant activity than thermal treatment. In addition, HHP treatments maintained higher aldehydes, alcohols and ketones concentrations than thermal treatment.	Chen and others (2015c)
Banana	Smoothie	350 to 550 MPa; 2 to 10 min; ~20 °C	Significant microbial reductions. Total aerobic bacteria inactivation seemed to increase with increasing pressure and treatment time. No significant difference in PPO and PME activities was observed after HPP at 550 MPa/10 min, indicating their pressure resistance.	Li and others (2015)
Beetroot	Juice	300 MPa; 0 to 10 min; 20 °C	3.5 log reduction of *S. cerevisiae* (NCFB 3191). No sublethal injury.	Sokołowska and others (2013b)
Black mulberry	Juice	200 to 600 MPa; 20 min; 25 °C	Two new anthocyanins [pelargonidin-3-*O*-coumaroylglucoside (0.46%) and delphinidin-3-*O*-coumaroylglucoside (5.8%)] were identified in the samples treated at 200 MPa. One new anthocyanin, delphinidin-3-*O*-coumaroylglucoside (5.38%), was detected in the juice treated at 400 MPa. At 600 MPa, no new anthocyanins were detected.	Engmann and others (2013)
Blueberry	Juice	200 to 600 MPa; 5 to 15 min; <42 °C	The microbial load after the HPP treatments was always below the detection limit. More than 92% ascorbic acid retention. Increase of total phenolic content. Color changes were not visually detectable.	Barba and others (2013)

(*Continued*)

Table 3–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
Carrot	Juice	500 and 600 MPa; 1 min; 20 °C	Reduction of the total counts by approximately 4 log CFU/mL. Complete inactivation of *L. monocytogenes* at 500 MPa.	Patterson and others (2012)
Carrot, celery, green pepper, lemon, olive, onion, tomato	Blended beverage	100 to 400 MPa; 120 to 540 s; <30 °C	High ascorbic acid retention. No significant changes of total phenolics.	Barba and others (2010)
Carrot, melon, orange, papaya	Smoothie	450 and 600 MPa; 3 min; 20 °C	Increase of the extractability of lycopene, β-carotene and polyphenols compared to untreated samples. Changes in bioactive compounds during the storage (45 d at 4°C) were lower in HHP smoothie than in the thermal-treated sample.	Andrés and others (2016c)
Carrot, melon, orange, papaya	Smoothie added with soymilk	550 and 650 MPa; 3 min; 20 °C	Little discoloration in HHP-treated samples after 45 d of refrigerated storage. High antioxidant capacity modulated mainly by ascorbic acid.	Andrés and others (2016a)
Carrot, melon, orange, papaya	Smoothie added with skim milk	450 and 650 MPa; 3 min; 20 °C	Complete inactivation of the naturally occurring microbiota. HPP maintained microbial stability until the end of the storage period (45 d at 4 °C). Soluble sugars, organic acids and minerals showed no significant changes after the treatments and storage. No significant differences were found in sensorial attributes between untreated and HPP samples.	Andrés and others (2016b)
Cashew apple	Juice	250 and 400 MPa; 3 to 7 min; 25 °C	HHP did not change pH, acidity, total soluble solids, ascorbic acid, or hydrolysable polyphenol contents. However, juice pressurized for 3 and 5 min showed higher soluble polyphenol contents. Antioxidant capacity was not altered by HHP, but when treated at 250 MPa for 3 min, it increased.	Queiroz and others (2010)
Chinese bayberry	Juice	500 MPa; 5 min; ~25 °C	89.2% and 96.5% of ascorbic acid and anthocyanin retention, respectively.	Wang and others (2015)
Chokeberry	Juice	200 to 600 MPa; 15 min; ~26 to 38°C	The pressure of 400 MPa was effective enough to distinctly increase the microbial stability of the product and to make the phenolic compounds more stable upon storage.	Błaszczak and others (2017)
Coconut	Water	400 to 600 MPa; 2 min; 4 °C	Microbial reduction of *E. coli* O157:H7, *Salmonella* Typhimurium (ATCC 14028), and *L. monocytogenes* by 6 log CFU/mL. No significant changes in the glucose, fructose, sucrose, and PPO activity after any of the treatments.	Lukas (2013)
Cranberry	Prebiotic juice fortified with FOS	450 MPa; 5 min; 11.5 °C	The treatment preserved FOS maintaining the prebiotic property of the juice.	Gomes and others (2017)
Cucumber	Juice	500 and 600 MPa; 2 min	Good preservation of color throughout storage.	Wang and others (2013)
Elephant apple	Juice	600 MPa; 5 min; ~35 °C	Acceptable levels of microbial inactivation were achieved, producing a juice with a shelf life of 60 d at 4 °C and with better sensory properties (odor and taste) than that of untreated samples.	Nayak and others (2017)
Grape	Juice	150 to 250 MPa; 5 to 15 min; 20 to 40 °C	As the temperature increased microbial inactivation also increased for a total of 5 to 7 log reduction. Storage of HHP-treated samples revealed no microbial growth up to 90 d. No 5-hydroxymethyl-2-furfural (HMF) was detected.	Mert and others (2013)
Grape	Wine	650 MPa; 0.25 to 2 h; 18 °C	Reduction of the contents of total phenolics, total anthocyanins, tartaric esters, flavonols, and tannins. HHP processing for 2 h significantly reduced the intensities of sour and fruity odor of wine.	Tao and others (2012)
Grapefruit	Juice	402 MPa; 3 min; ~32 °C	No effect on the levels of citric acid, flavonoids, limonoids and coumarins. No microbial growth for 28 ds.	Uckoo and others (2013)
Juçara, mango	Juice blend	600 MPa; 5 min; 25 °C	HHP did not cause a change in the anthocyanin content. High sensory acceptance.	Moreira and others (2017)
Kiwifruit, mango, orange, pineapple	Juice-blend mixed with milk or soymilk	400 MPa; 5 min; 40 °C	Bioaccessibility of ascorbic acid was not modified.	Rodríguez-Roque and others (2014)

(*Continued*)

Table 3–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
Litchi	Juice	100 to 300 MPa; 5 to 15 min; ~27 °C	Treatments at 300 MPa for 10 min and 15 min were found to enhance the shelf life of product up to 32 d as compared to 12 d of untreated during refrigerated storage.	Kaushik and others (2014)
Litchi	Probiotic juice	500 MPa; 2 min; ~25 °C	Compared with fermented heat-treated juice, fermented HHP-treated juice showed a better color, flavor and overall acceptance, and also retained more total phenolics and antioxidant capacity.	Zheng and others (2014)
Longan	Juice	500 MPa; 30 min; 25 °C	PPO showed higher rate of degradation and was more resistant to pressure than POD. Residual ascorbic acid in pressurized juice was still higher than that thermal treated juice throughout the subsequent storage period. No microbial growth.	Chaikham and others (2014)
Longan	Probiotic juice	500 MPa; 30 min; 25 °C	Positive effect of pressurized juice on increasing formation of lactic acid and total short-chain fatty acids as well as decreasing of ammonia formation by *Lb. acidophilus* LA5, *Lb. casei* 01.	Chaikham and others (2012)
Longan	Xanthan-added juice	300 and 500 MPa; 30 min; 25 °C	Pressurised juice at 500 MPa was brighter. PPO in pressurized juices at 300 and 500 MPa, were more than 100% and 95–99%, respectively.	Chaikham and Apichartsrangkoon (2012)
Longan, pennywort	Herbal-plant beverage added with rice (*Oryza sativa* L.)	400 MPa; 30 min; 25 °C	Pressurization could maintain the natural color and bioactive compounds of the product throughout a refrigerated storage for 4 wk.	Worametrachanon and others (2014)
Mandarin	Juice	150 to 450 MPa; 10 to 60 s; 15 to 45 °C	6.12 log reduction of *Lb. plantarum* (CECT 220) at 45 °C and at 400 MPa.	Carreño and others (2011)
Mango	Juice	250 to 550 MPa; 0 to 60 min; <25 °C	Total inactivation of *Leuconostoc mesenteroides* (ATCC 8293) was achieved by a 5 min treatment at 400 MPa. A 6 log reduction in *E. coli* O157:H7 (ATCC 43894) was observed at 400 MPa when treated for 10 min. At 500 and 550 MPa, there were no survivors after the 1 min.	Hiremath and Ramaswamy (2012)
Mango	Nectar	600 MPa; 1 min; ~38 °C	Significant inactivation of natural microorganisms. The activity of acid invertase was increased by 8.57%. A significant decrease in sugar content, as well as a significant increase in HMF and cloud.	Liu and others (2014)
Maoberry	Juice	400 and 600 MPa; 10 min; 25 °C	Complete inactivation of total plate count. Good preservation of color. A significant change of pH in low pressure treated juice (400 MPa) during refrigerated storage for 4 wk.	Chaikham (2015)
Melon	Juice	500 MPa; 20 min; 22 °C	After the treatment at 500 MPa for 20 min, POD, PPO and LOX in the juice decreased to about 78%, 9%, and 5%, respectively. No significant sensorial changes.	Ma and others (2010)
Mulberry	Juice	500 MPa; 5 min; ~25 °C	Total aerobic bacteria, yeasts and molds were not detected in HHP-treated juice for 28 ds at 4°C and 25°C.	Zou and others (2016)
Orange	Juice	150 to 350 MPa; 15 min; 22 °C	Total inactivation of *E. coli* (ATCC 11775) at relatively mild pressure of 200 MPa, and *L. innocua* (GIM1.230) and *Lb. plantarum* (GIM1.140) at 300 MPa.	Wang and others (2012a)
Orange	Juice mixed with milk	100 to 400 MPa; 120 to 540 s; <32 °C	A 5 log reduction of *Lb. plantarum* (CECT 220) was obtained after 200 MPa, 300 s. Ascorbic acid retention higher than 91%. Color changes increased when pressure and treatment times were higher.	Barba and others (2012a)
Orange, sweet pepper	Juice blend	550 MPa; 5 min; ~25 °C	About 4 log reduction of total aerobic bacteria, and yeasts and molds.	Xu and others (2015)
Papaya	Beverage	350 to 650 MPa; 5 and 10 min; <39.5 °C	After treatment at 550 and 650 MPa/5 and 10 min, the total aerobic bacteria counts yeasts and molds counts were not detected. The HHP-treated sample showed higher total carotenoids content, total phenols content and antioxidant capacity, compared with the thermal-treated sample during 40 d storage at 4 °C.	Chen and others (2015a)

(*Continued*)

Table 3–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
Peach	Juice	400 to 600 MPa; 5 to 25 min; 25 °C	At 500 and 600 MPa, PPO and PME enzymatic activities were inactivated significantly. All attributes of HHP-treated juice exhibited similar scores to untreated juice.	Rao and others (2014)
Pear	Nectar	0 to 241 MPa; 2 s and 0 to 15 min; ~25 °C	More than 1.2, 3.0, and 1.8 min of pressurization at 241 MPa would be required to improve the inactivation of *S. cerevisiae* (ATCC 10274), *E. coli* (ATCC 11775), and *L. innocua* (ATCC 51742), respectively.	Guerrero-Beltrán and others (2011)
Pennywort	Juice	500 MPa; 20 min; 30 °C	HHP preserves ascorbic acid, total phenolic compounds, and antioxidant capacity superior than pasteurization.	Chaikham and others (2013)
Pineapple	Juice	0 to 500 MPa; 20 min; <22 °C	About 20% reduction in allergenicity under 500 MPa.	Liang and others (2015)
Pomegranate	Juice	400 MPa; 5 min; <32 °C	Total inactivation of yeasts and molds. A great retention of the original color, anthocyanins and antioxidant capacity. Increase of total phenols.	Chen and others (2013)
Prickly pear	Juice	400 and 550 MPa; 0 to 16 min; ~25 °C	Increase of total phenolic content.	Jiménez-Aguilar and others (2015)
Pummelo	Juice	550 MPa; 10 min; ~25 °C	The total plate count, yeasts and molds were significantly decreased by 4.83 and 4.15 log CFU/mL and showed to be microbiologically safe during storage. The activity of PME and POD was inactivated by 22.5% or increased by 10.4%.	Gao and others (2015)
Purple sweet potato	Nectar	400 MPa; 10 min or 500 MPa; 5 min or 600 MPa; 2.5 min; ~25 °C	Inactivation of yeasts and molds below the detection limit, and the count of yeasts and molds in juice was kept lower than the detection limit during 12 wk of storage at 4 and 25 °C.	Wang and others (2012b)
Sea buckthorn	Juice	200 to 600 MPa; 5 to 40 min; 25 to 35 °C	HHP processing (600 MPa/5 min/35 °C) achieve a 90% PME enzyme inactivation. Slight increase in antioxidant activity at 200 to 600 MPa at 25°C.	Alexandrakis and others (2014)
Strawberry	Juice	600 MPa; 4 min; <43 °C	The total aerobic bacteria and the yeasts and molds were not detected after HHP treatments and during 6-mo storage at 4 and 25 °C. Significant decrease in ascorbic acid, anthocyanins, total phenols, and antioxidant.	Cao and others (2012)
Strawberry	Nectar	600 MPa; 0 to 10 min	HHP treatment for 4 min was sufficient to inactivate total aerobic bacteria, yeasts and molds in strawberry nectar without effects on the total soluble solids, pH, titratable acidity, color, total phenols and antioxidant activity. However, the contents of ascorbic acid and anthocyanins in HHP-treated nectar were significantly decreased by 9.2% and 20.6%, respectively. Moreover, the esters were significantly decreased and the alcohols increased after HHP treatment, but the aroma quality of strawberry nectar was better retained.	Xu and Liao (2011)
Sugarcane	Juice	200 to 600 MPa; 6 min; <38 °C	HHP at 600 MPa significantly reduced aerobic bacteria, coliform, and yeast counts. No differences when compared to the fresh juice in terms of physicochemical properties and sensory acceptance.	Huang and others (2015)
Sweet cherry	Juice	400 MPa; 5 min or 550 MPa; 2 min; 10 °C	Treatments reduced the microbiological load to undetectable levels without affecting total soluble solids and titratable acidity. Pressure treatments increased anthocyanins by 8%.	Queirós and others (2015)
Tomato	Juice	700 MPa; 10 min; 45 °C	HPP treatment significantly improved the extractability of lycopene over thermal processing and control. Microbial stability over a storage period of 52 wk at 4, 25, and 37 °C.	Gupta and others (2010)
Twistspine pricklypear	Juice	600 MPa; 10 min	Good preservation of antioxidant activity.	Moussa-Ayoub and others (2011)
Watermelon	Juice	20 to 600 MPa; 20 min; 400 MPa; 20 to 60 min or 10 to 40 min; 30 °C	The protein absorption decreased with prolonged exposure to HHP compared with control. High degree of change in structure of proteins along with the increase in interval frequency of HHP.	Liu and others (2015)
Wild cherry	Juice	100 to 500 MPa; 5 to 15 min; 25 °C	In pressurized juices at 100, 300, and 500 MPa, the PPO activities were 110% to 126%, 112% to 131%, and 81% to 90%, respectively. High levels of ascorbic acid, total anthocyanins, total phenols, and antioxidant capacity, as well retention of redness color.	Chaikham and Baipong (2016)

(*Continued*)

Table 3–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
		Pulsed-high hydrostatic pressure		
Litchi	Juice	300 to 600 MPa; 1 to 3 pulses × 1 s; 29 to 39 °C	Treatment resulted in increased activity of POD more than PPO.	Kaushik and others (2016)
Orange	Juice	250 MPa; 45 °C; 6 pulses × 60 s or 150 to 300 MPa; 25 to 45 °C; 6 and 10 pulses × 60 s	Higher pressure and temperature levels seem to not affect ascorbic acid content, which is, instead, influenced by the number of pulses applied. Optimum conditions (250 MPa, 45 °C, 6 pulses × 1 min) resulted in a minimum shelf life of 21 ds at 4 °C.	Donsì and others (2010)
		High-pressure homogenization		
Apple	Juice	20 MPa	The treatment caused a reduction of juice acceptability, as some consumers revealed strange odor and color.	Bevilacqua and others (2012b)
Apricot	Juice	100 MPa; <40 °C	Eight passes at 100 MPa allowed *Z. bailii* (strain 45) inactivation (2.5 log CFU/mL).	Patrignani and others (2010)
Carrot	Juice	100 MPa; <40 °C	Eight passes at 100 MPa allowed *Z. bailii* (strain 45) inactivation (2.5 log CFU/mL).	Patrignani and others (2010)
Cashew apple	Juice	25 to 150 MPa; 25 °C	Decrease of the juice consistency coefficient and yield stress (up to 50% and 30% of the original values, respectively). HPH also decreased the mean particle size and changed the particle size distribution.	Leite and others (2015)
Mandarin	Juice	30 to 120 MPa; 10 s; 15 and 30 °C	Microbial inactivation of *Lb. plantarum* (CECT 220) by 2.4 log CFU/mL after 120 MPa and 30 °C.	Carreño and others (2011)
Orange	Juice	100 MPa; 2 s; <48 °C	5 log reduction in *L. innocua* (CECT 910) population.	Belloch and others (2012)
Orange	Concentrated juice	0 to 150 MPa; 25 °C	HPH decreased the product consistency, with a reduction up to 50% on its apparent viscosity and 64% on its consistency index at −10 °C. The product color was unaffected by HPH.	Leite and others (2014)
Ortanique	Juice added with trehalose	20 and 100 MPa	HPH affects juice cloud influencing trehalose interactions.	Betoret and others (2017)
Pineapple	Juice	120 and 150 MPa	Homogenization reduced spores of *F. oxysporum* (DSMZ 2018) at the undetectable level only through a 3-step treatment at 120/150 MPa; treatments at 1 or 2 steps reduced *F. oxysporum* spores by 1 and 2 log CFU/mL, respectively.	Bevilacqua and others (2012a)
Strawberry	Juice	60 and 100 MPa	The treatment significantly increased the antioxidant capacity and total phenolic content.	Karacam and others (2015)
Tomato	Juice	0 to 100 MPa; ~27 °C	Increase of the consistency and decrease of particle sedimentation and serum separation.	Kubo and others (2013)
		Ultra-high-pressure homogenization		
Apple	Juice	100 to 300 Mpa	Low numbers of microorganisms were detected after treatment at 300 MPa.	McKay and others (2011)
Banana	Juice	0 to 400 MPa; <35 to 39 °C	Pressures higher than 200 MPa were required to obtain 4 log reduction of total mesophilic bacteria and pectate lyase inactivation.	Calligaris and others (2012)
Grape	Juice	250 MPa; 10 min	Increase of 14.6% and 16.2% in total phenolic content and radical scavenging activity value, respectively. No significant difference in the bioaccessibility of the total phenolics.	He and others (2016)
Mango	Nectar	200 and 300 Mpa	Good preservation of color.	Tribst and others (2011)
Orange	Juice	250 MPa; 10 min	Increase of 29% in total phenolic content and radical scavenging activity value. No significant difference in the bioaccessibility of the total phenolics.	He and others (2016)
Pineapple	Juice	50 to 250 MPa; 2 to 20 °C	A 3-passes treatment at 150 MPa seems to be sufficient to reach a microbial inactivation of *S. cerevisiae* (ATCC 16664), *E. coli* O157:H7 (ATCC 26), *Lb. delbrueckii* sp. *lactis* (ATCC 4797) (7 log CFU/mL).	Maresca and others (2011)
Tigernut	Beverage	200 and 300 MPa; 40 °C	UHPH-treated beverages showed better colloidal stability than the conventional treated. The treatments improved the oxidative stability of beverages.	Codina-Torrella and others (2017)
White mulberry	Juice	200 MPa; <35 °C	Significant reductions in the content of anthocyanins and phenolic acids, as well as antioxidant capacity value.	Yu and others (2014)

sensorial properties in terms of microstructure, rheological, and aroma profiles (Patrignani and others 2010) in different juices, such as tomato (Kubo and others 2013), orange (Leite and others 2014), and cashew apple juices (Leite and others 2015).

Overall, it is not easy to predict the effect of HPH technology on the properties of fruit products. Leite and others (2015) reported that each vegetable cell wall had a different behavior when processed by HPH. While carrot tissue requires higher shears to be disrupted, tomato cells could be broken at moderate values. This suggests that the effect of HPH processing is different for each vegetables product, and highlights the need for a better understanding of this process. In this respect, proton nuclear magnetic resonance (^{1}H NMR) spectroscopy has recently been proposed as a nondestructive and highly reproducible technology to better study the effects of HPH in juice processing (Betoret and others 2017).

Ultra-high-pressure homogenization

The effectiveness of UHPH (pressue up to 300 MPa) in fruit juices related to the inactivation of spoilage microorganisms and preservation of quality attributes is well documented (Maresca and others 2011; McKay and others 2011; Tribst and others 2011; Calligaris and others 2012; Yu and others 2014). This technology can improve the bioaccessibility of carotenoids, lycopene, calcium, and phosphorous by reducing the particle size distribution and inducing a high degree of cell-wall rupture (He and others 2016).

UHPH has been widely studied in milk and dairy products, but there are few references on its application in vegetable beverages (Codina-Torrella and others 2017).

Ultrasound Processing

Sonication

Sonication (ultrasound, US) might be used as an alternative processing option to conventional thermal approaches for pasteurization and sterilization of food products. The propagation of ultrasound in a liquid induces bubble cavitation due to pressure changes. These resulting micro-bubbles collapse, and induce a local increase of temperature and pressure. Thus, the intense local energy and high pressure bring about a localized pasteurization effect without causing a significant rise in macro-temperature (Jiménez-Sánchez and others 2017a).

Based on frequency range, the applications of ultrasound in food processing, analysis, and quality control can be divided into low and high energy. Low-energy (low-power, low-intensity) ultrasound has frequencies higher than 100 kHz at intensities below 1 W/cm^2. High-energy (high power, high-intensity) ultrasound uses intensities higher than 1 W/cm^2 at frequencies between 20 and 500 kHz (Shaheer and others 2014). An overview of the recent studies on this technology is reported in Table 4.

Sonication has been widely investigated as a mean to preserve fruit juices (Adekunte and others 2010; Gómez-López and others 2010; Cui and others 2012; Alighourchi and others 2014; Bevilacqua and others 2014; Mohideen and others 2015). Overall, the antimicrobial effects of US processing might be attributed to intracellular acoustic cavitations which cause an increase in the permeability of membranes therefore losing selectivity, thinning of cell membranes, localized heating, and production of free radicals (Farhadi Chitgar and others 2017). The lethal effect of US is reported to be dependent on the type of microorganism. Generally, cavitation is more effective on gram-positive bacteria, spores, spherical-shaped, and small round cells (Abdullah and Chin 2014).

However, various research groups have studied how sonication might affect physicochemical and nutritional parameters of products. Generally, low-power sonication tends to increase the level of bioactive compounds in sonicated food materials due to enhanced extraction of bound pigments as a result of cell wall disruption (Bhat and others 2011b), as reported for kasturi lime (Bhat and others 2011b), black mulberry (Jiang and others 2015), grapefruit (Aadil and others 2015b), and other juices (Khandpur and Gogate 2015). Interestingly, Costa and others (2013) evaluated the use of sonicated pineapple juice as a substrate to produce a probiotic beverage containing *Lactobacillus casei*. As a result, sonicated juice was shown to be a suitable substrate for probiotic microorganism cultivation and to design an alternative nondairy probiotic beverage.

A possible drawback of this approach is the degradation of some components at high power levels. For example, in watermelon juice, ascorbic acid, lycopene, and phenolic contents decreased significantly at higher amplitude levels and at the maximum processing time (Rawson and others 2011b). In jamun juice, anthocyanin degradation increased with increasing amplitude and time of exposure (Shaheer and others 2014). In a calcium-added orange juice, the ascorbic acid content decreased with sonication in a time-dependent manner (Gómez-López and others 2010).

Manosonication

The combination of high pressure with sonication could increase the effect of ultrasound (manosonication, MS; Jiménez-Sánchez and others 2017a). This can be assigned to different reasons, such as an increase in free radical production and higher bubble implosion (Sango and others 2014). The studies carried out by Guzel and others (2014) and Engmann and others (2014a) confirmed the suitability of MS for reducing spoilers and potential pathogens in apple, orange, and black mulberry juices.

However, it is important to determine the critical pressure level for achieving the maximum synergetic effect. Above this pressure, there is a decrease in the effectiveness, associated with a decrease of cavitation phenomena, because ultrasound waves are unable to overcome the combined cohesive forces of overpressure and the cohesive force of the liquid molecules (Sango and others 2014).

Osmosonication

Combination of US and high osmotic pressure has been named osmosonication (OS). Generally, this technology might be used in products where heat treatment can damage nutritional compounds such as vitamins (Sango and others 2014). OS has been reported as suitable strategy to produce orange and tropical highland blackberry juices with improved safety attributes (Wong and others 2010a,b).

Radiation Processing

Ultraviolet light

Among the nonthermal technologies developed in the last few decades, ultraviolet (UV) light processing is one of the most promising because it is easy to use and lethal to most microorganisms, and it is a dry cold process that can be effective at low cost in comparison with other preservation methods (Gayán and others 2012).

The wavelength range for UV light for food processing varies from 100 to 400 nm and is categorized as UV-A (320–400 nm), UV-B (280–320), and UV-C (200–280 nm). UV-C radiation is considered the germicidal region lethal to most types of microorganisms (Gayán and others 2012). Because the United States Food

Table 4–Ultrasound.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
		Sonication		
Apple	Juice	600 W; 60 to120 μm; 20 kHz; 3 to 9 min; 20 °C	The largest increase in consistency coefficient was determined after ultrasonic treatment at 60 μm/3 min.	Šimunek and others (2014)
Apple	Concentrated juice	330 W; 10 min.	Low efficiency of inactivation of *Al. acidoterrestris* spores.	Djas and others (2011)
Apple	Nectar	600 W; 60 to120 μm; 20 kHz; 3 to9 min; 20 °C	The largest increase in consistency coefficient was determined after ultrasonic treatment at 120 μm/3 min.	Šimunek and others (2014)
Apple, banana, orange, strawberry	Smoothie	1500 W; 20 kHz; 40% to 100%; 3 and 10 min	Sonication reduced color, rheological parameters and particle size. Satisfactory sensory acceptability scores.	Keenan and others (2012b)
Apple, carrot	Juice blend	1000 W; 20 kHz; 10 min; ~25 °C	Decrease of total aerobic counts.	Gao and Rupasinghe (2012)
Barberry	Juice	200 W; 70% and 100%; 20 kHz; 10 and 15 min; ~25 °C	Sonication significantly reduced microbial counts. A significant increase in the total phenol content and antioxidant activity. Sonication (at 70% of power) showed less effect on total anthocyanin and color of juice compared to thermal treatment.	Farhadi Chitgar and others (2017)
Black mulberry	Juice	650 W; 20 kHz; 30 min; ~20 °C	High preservation of total phenolics, anthocyanins, and antioxidant activity.	Jiang and others (2015)
Blueberry	Juice	500 W; 40% to 100%; 20 kHz; 25 °C	The highest log reduction in total aerobes (1.36 log CFU/mL) was achieved with high intensity (100 amplitude) sonication condition. Good preservation of anthocyanins and color.	Mohideen and others (2015)
Blueberry	Nectar	600 W; 60 to 120 μm; 20 kHz; 3 to 9 min; 20 °C	The largest increase in consistency coefficient was determined after ultrasonic treatment at 120 μm/3 min	Šimunek and others (2014)
Blueberry, orange, pomegranate	Juice blend	130 W; 60%; 20 kHz; 4 and 6 min; <40 °C	The effect of US relied upon the yeast, being *W. anomalus* (DSM 70130) less affected by the treatment. The effect of the kind of microorganism was not significant when a stronger treatment was used as the yeasts showed similar trend being reduced by 1.6 to 2.6 log CFU/mL.	Bevilacqua and others (2014)
Bottle gourd	Juice	500 W; 50 kHz; 50% to 90%; 10 to 30 min; and 500 W; 20 to 50 kHz; 70%; 30 min; 25 °C	Change in amplitude and frequency showed not significant decline in pH. Increase in amplitude led to significant increase in carotenoid at 70% for 20 minutes. Significant change in particle size and distribution.	Bhat and Sharma (2016)
Carrot	Juice	100 W; 50%; 20 kHz; 15 min; <30 °C	Nutrient analysis of the ultrasound treated juice showed that the samples were similar to fresh juice.	Khandpur and Gogate (2015)
Cranberry	Juice	600 W; 20 kHz; 60 to 120 μm; 3 to 9 min; 20 °C	Sonication is not very effective against *Al. acidoterrestris* DSM 3922.	Režek Jambrak and others (2017)
Cranberry	Nectar	600 W; 60 to 120 μm; 20 kHz; 3 to 9 min; 20 °C	Largest increase in consistency coefficient was determined after ultrasonic treatment at 60 μm/3 min.	Šimunek and others (2014)
Grape	Wine	40 kHz; 10 and 20 min	50.89% and 59.80% cells lethal rate of *S. cerevisiae* (QA23) after 10 and 20 min, respectively.	Cui and others (2012)
Grapefruit	Juice	600 W; 70%; 28 kHz; 30 to 90 min; 20 °C	Significant increase in total carotenoids, lycopene, sugar contents, and phenolic compounds, whereas a decrease in viscosity and microorganisms were found in all the juice samples sonicated for 30, 60, and 90 min as compared to control.	Aadil and others (2015b)

(*Continued*)

Table 4–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
Jamun	Juice	80% and 100%; 5–10 min	Anthocyanin degradation increase with increasing amplitude and time of exposure.	Shaheer and others (2014)
Kasturi lime	Juice	700 W; 70%; 25 kHz; 0 to 60 min; 20 °C	Sonication showed enhancement in bioactive compounds (antioxidants) with significant reductions in the microbial counts, all of which were time-dependent.	Bhat and others (2011a)
Kiwifruit	Juice	180 W; 40 kHz; 10 and 30 min; ~20 °C	At d 7 of refrigerated storage, ultrasound treatments for 10 and 30 min showed significant reductions on yeasts and molds counts with respect to untreated sample (0.96 and 1.40 log reductions, respectively).	Tomadoni and others (2016)
Mango	Juice	68 to 72 W; 40 kHz; 15 to 60 min; 25 °C	The shelf life of sonicated juice stored at 4 °C was prolonged by 4 wk.	Santhirasegaram and others (2015b)
Mango, papaya	Juice blend sweetened with *Stevia rebaudiana*	400 W; 24 kHz; 100%; 20 and 160 s	High retention of the ascorbic acid content (84% to 91%) after sonication processing. Higher treatment time of ultrasound led to a higher carotenoid content.	Carbonell-Capella and others (2016)
Orange	Juice	100 W; 50%; 20 kHz; 15 min; <30 °C	Nutrient analysis of the ultrasound treated juice showed that the samples were fresh-like.	Khandpur and Gogate (2015)
Orange	Juice with calcium-added	500 W; 50% to 75%; 20 kHz; 2 to 10 min; 10 °C	The treatment decreased aerobic mesophilic count by 1.38 log CFU/mL, and yeasts and molds counts by 0.56 log CFU/mL. The ascorbic acid content decreased with sonication in a time-dependent manner.	Gómez-López and others (2010)
Peach	Juice	1000 W; 20 kHz; 0 to 15 min; ~22 °C	Although the pulp sedimentation is highly reduced by the process, both juice consistency and serum cloudiness (turbidity) showed an increase, followed by a decrease and then a new increasing in relation to the processing time. The color of the processed samples showed a slight increase in the lightness parameter, with small changes during 21 d of storage at 25 °C.	Rojas and others (2016)
Pear	Juice	500 W; 25 kHz; 70%; 0 to 60 min; 25 °C	Ultrasound processing of pear juice resulted in enhanced phenolic compounds, ascorbic acid, antioxidant capacity, sugar contents, mineral elements and microbial safety without inducing any change in pH, acidity, and total soluble solids. The ultrasound-treated juice samples exhibited better quality at treatment times of 45 and 60 min.	Saeeduddin and others (2016)
Pineapple	Probiotic juice	500 W; 19 kHz; 10 min	Sonication can be applied as a pretreatment for cultivating the probiotic strain *Lb. casei* (NRRL B442), which was then able to ferment sonicated pineapple juice without any nutrient supplementation.	Costa and others (2013)
Pomegranate	Juice	20 kHz; 50% to 100%; 0 to 15 min; ~25 °C	Lower amplitude levels (50% and 75%) did not inactivate *E. coli* (RITCC 1177) and *S. cerevisiae* (PTCC 5052) significantly (<1.5 log reduction), whereas at 100% power for 15 min, their populations were reduced by 3.47 and 1.86 log CFU/mL, respectively.	Alighourchi and others (2014)

(*Continued*)

Table 4–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Key finding(s)	Reference
Sour cherry	Juice	700 W; ~20 kHz; 10 min	Increasing the probe diameter from 20 to 30 mm caused a decrease in the total microbial count while further increase from 30 to 40 mm resulted in elevated total microbial count.	Samani and others (2013)
Strawberry	Juice	600 W; 60 to 120 μm; 20 kHz; 3 to 9 min; 25 °C	Low anthocyanin degradation.	Dubrović and others (2011)
Sweet lime	Juice	100 W; 50%; 20 kHz; 15 min; <30 °C	Nutrient analysis of the ultrasound treated juice showed that the samples were similar fresh juice.	Khandpur and Gogate (2015)
Spinach	Juice	100 W; 50%; 20 kHz; 15 min; <30 °C	Nutrient analysis of the ultrasound treated juice showed that the samples were similar to the fresh juice.	Khandpur and Gogate (2015)
Tomato	Juice	1500 W; 24.4 to 61.0 μm; 20 kHz; 2 to 10 min; <39.9 °C	A >5 log reduction of *P. fermentans* (DSM 70090) with increasing amplitude level in 10 min or less.	Adekunte and others (2010)
Watermelon	Juice	1500 W; 24.4 to 61 μm; 20 kHz; 0 to 10 min; 25 to 45 °C	Ascorbic acid, lycopene and phenolic content decreased significantly at higher amplitude levels and at the maximum processing time. Decrease in the phenolic content of sonicated juice when the temperature was increased from 25 to 45 °C.	Rawson and others (2011b)
			Manosonication	
Apple	Juice	450 W; 46.5 to 130.5 μm; 20 kHz; ~35 °C; 0 to 200 kPa	The bacterial cell inactivation rates of *L. monocytogenes* (STCC 5672) and *E. coli* O157:H7 (VTEC-Phage type 34) increased with increases in ultrasonic wave amplitude and pressure.	Guzel and others (2014)
Black mulberry	Juice	24 to 26 kHz; 10 to 20 min; ~10 °C; 200 to 600 MPa	Optimal treatment conditions were: 25 kHz, 15.35 min, 376.36 MPa, and 10.01 min (ultrasound frequency, ultrasound time, pressure and pressurizing time, respectively). At these optimum levels, manosonication ensure an high overall quality (bacteria and yeasts reduced to below the detection limit).	Engmann and others (2014a)
Blueberry	Juice	560 W; 350 MPa	5.2 log reduction of *E. coli* O157:H7	Zhu and others (2017)
Orange	Juice	450 W; 46.5 to 130.5 μm; 20 kHz; ~35 °C; 0 to 200 kPa	The bacterial cell inactivation rates of *L. monocytogenes* (STCC 5672) and *E. coli* O157:H7 (VTEC-Phage type 34) increased with increases in ultrasonic wave amplitude and pressure.	Guzel and others (2014)
			Osmosonication	
Orange	Juice	~50 W; 48 μm; 20 kHz; 0 to 20.4 min; ~25 °C; 12.6 MPa	A 5 log reduction of *Salmonella* cocktail strains (*S.* Typhimurium strain ATCC 14028, *Salmonella* Typhi strain ATCC 6539 and *Salmonella* Enteritidis strain ATCC 13076) after 48 h of storage at −18 °C.	Wong and others (2010a)
Tropical highland blackberry	Juice	~50 W; 48 μm; 20 kHz; 0 to 20.4 min; ~25 °C; 12.6 MPa	*Lb. casei* subsp. *rhamnosus* (ATCC 11981), yeasts (*S. cerevisiae* and *Zygosaccharomyces* sp.), and molds (*Aspergillus* sp. and *Penicillium* sp.) were reduced by 1.60 to as much as 5.01 log. For pathogens (*Salmonella* strains (*Salmonella* Typhi [ATCC 6539], *Salmonella* Enteritidis [ATCC 13076], and *Salmonella* Typhimurium [ATCC 14028]); *Shigella* sp.), reductions were total ≥7.1 log after 24 h of storage at −18 °C.	Wong and others (2010b)

Table 5–Radiation.

Fruit/vegetable source(s)	Product	Treatment conditions	Key finding(s)	Reference
		Ultraviolet light		
Apple	Juice	75 mJ/cm^2; 222, 254, and 282 nm; 20 °C	Inactivation of *E. coli* O157:H7 following exposure to 222 nm (2.81 log CFU/mL) was higher than the inactivation caused by 254 nm (1.95 log CFU/mL) and 282 nm (1.83 log CFU/mL). No reactivation was observed.	Yin and others (2015)
Apple	Cider	14 mJ/cm^2; 254 nm	Reduction of *E. coli*.	Usaga and others (2014)
Apple, cranberry	Juice blend	5.3 J/cm^2; 254 nm; 30 s	About 2 to 6 log reduction of *E. coli* (K 12 DSM 1607) and *P. fermentans* (DSM 70090).	Palgan and others (2011)
Ashitaba	Juice	254 nm	UV treatment might prolong the shelf life of juice without any problems in flavor and color, with low total bacteria and coliform bacteria numbers.	Kwon and others (2010)
Carrot	Juice	3.67, 4.69, and 6.50 kGy; 254 nm	6.50 kGy treatment reduced the number of microbes to undetectable levels. After 3 d of refrigerated storage, the sensory scores of UV-treated juice was superior to those of the control.	Jo and Lee (2012)
Carrot	Beverage	13.2 to 79.2 J/cm^2; 5 to 30 min	Maximum logarithmic reductions for mesophiles and total coliforms were ~3.2 and 2.6, respectively, after 30 min of UV light processing. Total soluble solids, pH, and titratable acidity were not affected by UV treatment. Beverages were well accepted by judges.	Hernández-Carranza and others (2016)
Carrot, orange	Juice blend	10.62 J/cm^2; 1 min	The application of UV caused marginal inactivation of PME (18% inactivation).	Caminiti and others (2012)
Coconut	Young and mature liquid endosperm mixed beverage	254 nm	5-Reduction of *Salmonella enterica* and natural microorganisms. The sensory quality scores of the processed beverage were not significantly different from the control.	Gabriel and others (2015)
Grape	Juice	0 to 100.48 kJ/L; 253.7 nm or 0 to 71.51 kJ/L; 290 to 315 nm	2 log reduction of total aerobic plate count as well as yeasts and molds. With the exception of viscosity and color, the values of the physical and physiochemical properties of juice were largely unchanged.	Müller and others (2014)
Grape	Concentrated juice	0 to 367 J/L; 254 nm	4.60 log reduction (99.99%) of *Al. acidoterrestris* (K47) spores for a dosage 367 J/L.	Groenewald and others (2013)
Grape	Wine	0 to 3672 J/L; 254 nm	A dosage of 3672 J/^{L} resulted in an average log microbial reduction of *Lb. plantarum* (strain 130), *Pd. acidilactici*, *O. oeni* (strain 48), *Acetobacter aceti* (DSM 3509^T), *S. cerevisiae* (VIN13), *Br. bruxellensis* (ISA 1649) of 4.97 and 4.89 in Chardonnay and Pinotage, respectively.	Fredericks and others (2011)
Grapefruit	Juice	0 to 3.94 J/cm^2; 254 nm	UV treatment caused a significant decrease (15% to 30%) in ascorbic acid and antioxidant capacity (10% to 27%). The microbiological quality of juices treated with 3.94 J/cm^2 was maintained for 15 and 10 d at 4 and 10 °C, respectively.	La Cava and Sgroppo (2015)
Guava	Nectar	0 to 24 J/mL; 253.7 nm	Inactivation of natural microorganisms increased with fluence. Negative effects on fresh-like sensory attributes.	Guevara and others (2012)
Kale	Juice	254 nm	UV treatment can prolong the shelf life of juice without any problems in flavor and color, with low total bacteria and coliform bacteria numbers.	Kwon and others (2010)
Lime	Juice	254 nm; 22.76 to 44.24 mJ/cm^2; 48.03 to 87.96 s	pH values of lime juice did not change while total soluble solids, turbidity, titratable acidity, sweetness, and color values of lime juice did change after UV treatments. Changes in quality index indicators were significant for UV dosage of 44.24 mJ/cm^2.	Mohd-Hanif and others (2016)
Lemon	Juice	200 to 400 nm; 0 to 60 min	Total phenolic and antioxidant capability were significantly decreased. Increase of ascorbic acid degradation.	Rameshkumar and others (2012)
Lemon, melon	Juice blend	2.46 J/mL; 254 nm; 16.53 °C	Reduction of *E. coli* K12 (ATCC 25253) population by >6 log CFU/mL.	Kaya and others (2015)
Mango	Juice	3.525 J/m^2; 15 to 60 min; ~25 °C	UV treatment reduced coliform counts below detection limits. For aerobic plate count, up to 45% reduction of microbial load. Significant improvement in antioxidant activities and extractability of carotenoids, phenolic compounds, and flavonoids, when compared to freshly squeezed juice.	Santhirasegaram and others (2015a)

(*Continued*)

Table 5–Continued.

Fruit/vegetable source(s)	Product	Treatment conditions	Key finding(s)	Reference
Nectarine	Juice	250 nm; 0 to 120 min; 12 to 45 °C	UV processing did not produce HMF.	Aguilar and others (2015)
Orange	Juice	0 to 108.42 mJ/cm^2; 254 nm; 3 to 20 min	Resistance of yeasts to UV light and existence of suspended particles limited the effectiveness of the process. The UV exposure time was found to be a key-feature on survival number	Hakguder Taze and others (2015)
Papaya	Juice	200 to 400 nm; 0 to 60 min	Total phenolic and antioxidant capability were significantly decreased. Increase of ascorbic acid degradation.	Rameshkumar and others (2012)
Passion fruit	Nectar	0 to 11 J/mL; 253.7 nm	Microbial inactivation increased with fluence. Negative effects on fresh-like sensory attributes.	Guevara and others (2012)
Peach	Nectar	203 kJ/m^2; 254 nm/0 to 60 min; ~25 °C	4 and 3 log reductions for *A. flavus* and *A. niger*, respectively. Slight variations in the characteristics of the nectar.	Flores-Cervantes and others (2013)
Pear	Juice	250 to 740 nm; 120 min; 25 °C	After 20 min, it was possible to reduce the PPO activity by 50%.	Falguera and others (2014)
Pineapple	Juice	10.76 mJ/cm^2	A significant reduction of 1.91 log CFU/mL in total plate count and 1.4 log CFU/mL in yeasts and molds. Preservation of physico-chemical characteristics.	Shamsudin and others (2014)
Pitahaya	Juice	254 nm	Total plate count and yeasts and molds counts achieved 2.43 and 2.7 log reductions, respectively.	Halim and others (2012)
Pitaya	Juice	57 μW/cm^2; 5 to 30 min	A substantial reduction of phenolic compounds (11.6%), betalains (14.6%), and antioxidant activity (37.0%), as well as 1.8 log CFU/mL of *Z. bailii*.	Ochoa-Velasco and Guerrero Beltrán (2013)
Pomegranate	Juice	12.47 to 62.35 J/mL	Reduction of aerobic plate count, yeast and mold count and *E. coli* (ATCC 25922) by 1.8, 1.45, and 6.15 log CFU/mL, respectively. After UV treatment, total monomeric anthocyanin content of juice did not change significantly.	Pala and Toklucu (2011)
Pummelo	Juice	572.45 W/m^2; 254 nm	The inactivation rate of *Salmonella* Typhimurium is negatively related to absorption coefficient of juice.	Shah and others (2014)
Starfruit	Juice	2.158 J/m^2; 254 nm/30 and 60 min; ~25 °C	Except for the ascorbic acid, other antioxidants measured showed enhancement on expsoure to UV (significant at 60 min). Reduction of aerobic plate count, yeasts and mold counts by 2 log.	Bhat and others (2011b)
Strawberry	Juice	254 nm; 15 to 60 min; ~25 °C	Decrease in pH, total soluble solids and titratable acidity. Increase of color parameters and clarity of juice. Reduction by 2 log CFU/mL in aerobic plate count and in total yeast and mold counts.	Bhat and Stamminger (2015b)
Tigernut	Beverage	253.7 nm; ~27 °C	The fat content and its oxidation level remained unaffected. The antioxidant capacity of treated samples decreased with increasing doses of UV-C. UV-C effectively inactivated up to 3 log CFU/mL of spoilage-related microorganisms (yeasts and molds, mesophilic flora and psychrotrophic bacteria). Horchata's freshness was extended to 4 d if samples were UV treated.	Corrales and others (2012)
Tomato	Juice	254 nm; 2.16 J/m^2; 15 to 60 min; 25 to 26 °C	UV was able to enhance certain bioactive compounds and their activity (total phenolics content, DPPH radical scavenging activity), while a few were degraded (total lycopene and ascorbic acid contents).	Bhat (2016)
Watermelon	Juice	2.7 to 37.5 J/mL; 254 nm/10 °C	37.5 J/mL treatment reduced total aerobes and yeasts and molds by 1.47 and 0.99 log CFU/mL, respectively. No-significant effects on quality parameters.	Feng and others (2013)
		Titanium dioxide-ultraviolet photocatalysis		
Apple	Juice	16 W; 0.82 and 8.45 J/cm^2; 254 nm	The population of *L. monocytogenes* (ATCC 15313) was reduced significantly to 6.0 and 3.9 log CFU/mL using 0.82 and 8.45 J/cm^2 treatments, respectively. The counts for *S. aureus* (ATCC 25923) also decreased significantly to 5.5 and 3.7 log CFU/mL using 0.82 and 8.45 J/cm^2 treatments alone.	Shahbaz and others (2016)

(*Continued*)

Table 5–Continued.

Fruit/vegetable source(s)	Product	Treatment conditions	Key finding(s)	Reference
Ashitaba	Juice	35 W; 25 mW/cm^2; 254 nm	Moderate inactivation of yeasts and molds, coliform bacteria, *Pseudomonas*, and *Bacillus cereus* after processing. During refrigerated storage, microbial populations in processed juice changed similarly to populations in un-processed sample.	Chai and others (2014)
		Gamma irradiation		
Ashitaba	Juice	0 to 5 kGy	At 5 kGy 2 log reduction in the viability of natural microorganisms. The content of flavonoids did not change, whereas polyphenols increased upon irradiation. Juices without irradiation (control) scored lower than the irradiated samples after 1 d.	Jo and others (2012)
Carrot	Juice	0 to 5 kGy	5 kGy of gamma irradiation reduced the number of natural microorganisms below the detection limit. After 3 d of refrigerated storage, the sensory scores of gamma-irradiated juice was higher to control.	Jo and Lee (2012)
Coconut	Water	5 kGy; ~10 °C.	Increase in turbidity after processing. After four wk of refrigerated storage, the absorbance of the irradiated samples did not show any appraisable change, as well as total carbohydrate content.	Awua and others (2011)
Kale	Juice	0 to 5 kGy	At 5 kGy 2 log reduction in the viability of natural microorganisms. The content of flavonoids did not change, whereas polyphenols increased upon irradiation. Juices without irradiation (control) scored lower than the irradiated samples after 1 d.	Jo and others (2012)
Mango	Juice	0 to 3 kGy; room temperature	No significant effect on the physico-chemical properties. Irradiation at doses of 1 kGy and above inhibited the growth of bacteria, yeasts and molds.	Naresh and others (2015)
Mango	Wine	0.5 to 3 kGy; ~26 °C	Increase of total phenolic and total flavonoid content in a dose dependent manner. Significant increase in the concentration of certain polyphenolic compounds with the exception of ellagic acid. No microbe was detected with a dose of 3 kGy.	Kondapalli and others (2014)
Papaya	Nectar	5 and 7.5 kGy	Irradiation resulted in a significant reduction of ascorbic acid content.	Parker and others (2010)
Papaya, strawberry	Nectar blend	2.5 to 10 kGy	22.9% to 30.2% ascorbic acid losses. Irradiation resulted in several antagonistic relationships, making it undesirable in terms of ascorbic acid concentration retention.	Swada and others (2016b)
Pomegranate	Juice	0 to 3 kGy.	1 kGy reduced *E. coli* (RITCC 1177) by 6.66 log CFU/mL, whereas at 3 kGy gamma irradiation reduced *S. cerevisiae* (PTCC 5052) by 5.08 log CFU/mL	Alighourchi and others (2014)
Sour cherry	Juice	0 to 6 kGy	3 kGy treatment improves the shelf life of juice and contribute to an overall reduction in microbial loads. Due to the results of physicochemical properties and antioxidant and microbial analyses, irradiation of juice at dosage of higher than 3.0 kGy is not recommended.	Arjeh and others (2015)
Strawberry	Nectar	2.5 to 10 kGy	Irradiation resulted in a great increase in antioxidant capacity (190.51 to 287.68 μmol Trolox equivalents/kg), with moderate effects on carotenoid concentration.	Swada and others (2016a)
Sugarcane	Juice	0.25 to 1.0 kGy	Irradiation has a positive contribution in preservation of juice at room and at low temperature storage.	Sankhla and others (2012)

(*Continued*)

Table 5–Continued.

Fruit/vegetable source(s)	Product	Treatment conditions	Key finding(s)	Reference
Yam	Juice	0 to 5 kGy	Yeast and molds were inactivated at 3 kGy. Irradiation reduced sample viscosity. Sensory evaluation testing revealed no significant difference between control samples and those irradiated with 1 kGy, except in color and texture.	Song and others (2010)
Watermelon	Juice	1 to 5 kGy; ~25 °C	Reduction of total bacterial counts in irradiated juice at 5 kGy. Improvement of antioxidant activity as well as color of the juice, without any adverse change in bioactive and volatile compounds qualities.	Eissa and others (2014)
			Pulsed light	
Apple	Juice	2.4 to 71.6 J/cm^2; <12 °C	In commercial apple juice, up to 3.0 and 4.4 log reductions for *Al. acidoterrestris* (ATCC 49025) spores and *S. cerevisiae* KE162 cells, respectively. In natural squeezed juice, only 1.5 and 2 log reduction for *Al. acidoterrestris* spores and S. *cerevisiae cells*, respectively.	Ferrario and others (2015)
Apple, cranberry	Juice blend	1.213 J/cm^2	About 3 to 4 log reduction of *E. coli* (K 12 DSM 1607) and *P. fermentans* (DSM 70090).	Palgan and others (2011)
Carrot, orange	Juice blend	3.3 J/cm^2; 360 μs; <30 °C	113% PME residual activity.	Caminiti and others (2012)
Grape	Juice	0.97 to 29.21 J/cm^2	Up to 1.9 log reduction of *Ps. aeruginosa* (ATCC 10145).	Hwang and others (2015)
Plum	Juice	0.97 to 29.21 J/cm^2	Up to 7 log reduction of *Ps. aeruginosa* (ATCC 10145).	Hwang and others (2015)
Melon	Juice	2.4 to 71.6 J/cm^2; 2 to 60 s; <20 °C	Overall, 0.3 to 6.9 log reduction of natural-occurring microorganisms.	Ferrario and others (2013)
Orange	Juice	1.8 to 5.5 J/cm^2	Up to 2.90 and 0.93 log-reduction for *E. coli* (DH5-α) and *L. innocua* (11288), respectively. Sublethally injured cells were also detected for both bacterial strains.	Pataro and others (2011)
Strawberry	Juice	2.4 to 71.6 J/cm^2; 2 to 60 s; <20 °C	Less than 1 log reduction for all microorganisms studied (*E. coli* ATCC 35218; *L. innocua* ATCC 33090, *Salmonella* Enteritidis MA44, and *S. cerevisiae* KE162)	Ferrario and others (2013)
			Electron beam irradiation	
Apple	Juice	0 to 0.7 kGy	0.7 kGy irradiation reduced numbers of exponential- and stationary-phase cells of *E. coli* O157:H7 by ~4.32 and 3.74 log CFU/mL, respectively, whereas starved cells were reduced by only 2.20 log CFU/mL. Exponential-phase cells exhibited the lowest resistance to irradiation, and sublethal injury in survivors of this group was higher than that of stationary-phase or starved cells irradiated at 0.5 or 0.7 kGy.	Hong and others (2014)

and Drug Administration (USFDA) has approved the use of UV-C light for fruit juices pasteurization, this technology has been largely applied to liquid foods and beverages (Tremarin and others 2017). Table 5 shows an overview of the effects of UV radiation on fruit and vegetable juices and beverages.

There are some data on the microbial inactivation, including pathogens (Pala and Toklucu 2011; Gabriel and others 2015), fungi (Flores-Cervantes and others 2013), and spoilage microorganisms (Fredericks and others 2011; Ochoa-Velasco and Guerrero Beltrán 2013); however, mathematical modelling of inactivation kinetics due to radiation effect is limited and requires investigation (Tremarin and others 2017).

Recently, several studies reported on minimal changes in nutritional and quality attributes of UV-treated products. Kwon and others (2010) found that UV treatment on kale juice prolonged the shelf life without any problems in flavor and color. Significant improvement in antioxidant activities and extractability of carotenoids, phenolic compounds, and flavonoids, were found in mango juice by Santhirasegaram and others (2015a). UV-C significantly increased the shelf life of tigernut beverage (Corrales and others 2012).

However, in some sensitive products such as guava and passion fruit nectars, sensory changes might be a drawback (Guevara and others 2012). Other negative effects could be the decrease of phenolic compounds, betalains, and antioxidant activity in pitaya juice (Ochoa-Velasco and Guerrero Beltrán 2013), or in the decrease of viscosity and the color change of grape juice (Müller and others 2014). A challenge is the formation of furans in apple juice or in juice-simulating media (Bule and others 2010; Müller and others 2013). The effects of this compound have not been addressed, although Müller and others (2013) reported that UV-treated juices did not increase their genotoxic effects towards Caco-2 cells. Another possible limit of UV treatment could be the high residual activity of enzymes (ca. 95%; Müller and others 2013).

Titanium dioxide-ultraviolet photocatalysis

Titanium dioxide-ultraviolet photocatalysis (TUVP) can inactivate pathogens under aqueous conditions by the generation of strong oxidizing agents using UV light (Shahbaz and others 2016). These agents include hydrogen peroxide and hydroxyl/hydroperoxyl radicals that are reactive toward biological macromolecules and, subsequently, lead to cell death (Chai and others 2014).

The effect of this technology on inactivation of microorganisms in commercial apple juice and ashitaba juice have been investigated by Shahbaz and others (2016) and Chai and others (2014), respectively. However, more studies are required to determine inactivation effects on a broad range of pathogenic and spoilage-causing microorganisms in various kinds of food matrix besides studying different quality attributes of end product (Shahbaz and others 2016).

Gamma (γ) irradiation

Irradiation of food products has been used in 56 countries and their safety has been approved by the World Health Organization (WHO), the Center for Disease Control and Prevention (CDC), the United State Dept. of Agriculture (USDA), and Food and Drug Administration (FDA; Alighourchi and others 2014).

Traditionally, γ-irradiation (GI) is known to be effective in reducing microorganisms in foods (Eissa and others 2014). Microorganisms are inactivated by GI primarily due to DNA damage. Several factors such as the composition of the medium, moisture content, presence or absence of oxygen, could affect the resistance to radiation, particularly in the case of vegetative cells (Jiménez-Sánchez and others 2017a). The impact of GI on microbiological and quality aspects of some fruit and vegetable juices and beverage products is listed in Table 5.

Alighourchi and others (2014) reported that GI at 1 kGy reduced *E. coli* in pomegranate juice by 6.66 log CFU/mL, whereas at 3 kGy it reduced *Saccharomyces cerevisiae* by 5.08 log CFU/mL. In ashitaba and kale juices, irradiation at 5 kGy induced a 2 log reduction of the naturally occurring microbiota, and this effect was maintained during the storage for 7 d under refrigerated conditions (Jo and others 2012). GI was also tested in sour cherry (Arjeh and others 2015), mango (Naresh and others 2015), and carrot juices (Jo and Lee 2012), as well as in mango wine (Kondapalli and others 2014).

Recently this technique has received considerable attention for maintaining quality attributes of processed beverages (Arjeh and others 2015). According to Swada and others (2016a), GI resulted in a great increase in antioxidant capacity, with moderate effects on carotenoid concentration in strawberry nectar (Swada and others 2016a). Other positive effects are reported for carrot (Jo and Lee 2012), and watermelon (Eissa and others 2014) juices, coconut water (Awua and others 2011), and mango wine (Kondapalli and others 2014).

However, GI might result in some drawbacks, like the reduction of viscosity in yam juice (Song and others 2010), or in a decrease of ascorbic acid in papaya nectar (Parker and others 2010) and papaya/strawberry nectar blend (Swada and others 2016b). A challenge of irradiation, as reported some years ago by Fan (2005), was the production of a furan derivative from sugars, or ascorbic acid. This issue was later confirmed by Nuncio-Jáuregui and others (2015). Furan derivatives were also found in thermally treated juices (Fan 2005).

Pulsed light

Pulsed light (PL) has been intensely investigated as an alternative to thermal treatments for killing pathogenic and spoilage microorganisms (Maftei and others 2015). This technology uses short time pulses (100 to 400 ms) of an intense broad spectrum between 100 and 1100 nm with 54% of emitted energy in the UV range (Ferrario and others 2015).

PL application in fruit juices is very promising as reported in Table 5. Palgan and others (2011) reported about 3 to 4 log reduction of *E. coli* K12 and *Pichia fermentans* in apple/cranberry juice blend. Hwang and others (2015) found 1.9 and 7 log reduction of *Pseudomonas aeruginosa* in grape and plum juices, respectively. In commercial apple juice, Ferrario and others (2015) achieved up to 3.0 and 4.4 log reductions for *Alicyclobacillus acidoterrestris* spores and *S. cerevisiae* cells, respectively. Exposure to PL causes the formation of pyrimidine dimers which impairs the process of cell replication (photochemical mechanism). Moreover, membrane disruption was also reported as a result of a momentous overheating. This phenomenon is attributed to a difference in UV light absorption between the microorganism and its surrounding environment (photothermal effect). Besides, structural damage in microbial cells like cytoplasmic membrane shrinkage was also reported (photophysical effect). It is possible for these mechanisms to coexist; the relative importance of each one would depend on the fluence and target microorganism (Ferrario and others 2015).

However, the lethal effect of PL processing depends on the type of microorganism and the absorption properties of the liquid food (Pataro and others 2011). For example, in strawberry juice PL

treatment lacked of effectiveness as less than 1 log-reduction was achieved for all microorganisms studied (*E. coli*, *Listeria innocua*, *Salmonella* Enteritidis, and *S. cerevisiae*) (Ferrario and others 2013). Similarly, in natural squeezed juice, only 1.5 and 2 log reduction were obtained for *Al. acidoterrestris* spores and *S. cerevisiae* cells, respectively (Ferrario and others 2015).

One of the potential drawbacks of PL application is that there is not a great deal of information on the occurrence of sublethal damage to bacterial cells following exposure to PL as well as the influence of treatment conditions on the extent of damage (Pataro and others 2011). In addition, another potential drawback is the generation of heat during prolonged treatments, a detrimental fact to the quality and nutritive value of the food that must be balanced by the implementation of a cooling system (Ferrario and others 2014).

Electron beam irradiation

Electron beam irradiation (EBI) is a novel food decontamination technology that uses low-dose ionizing radiation in the treatment of seeds or food, to eliminate microbial contamination. Additionally, EBI inhibits the germination of crops and controls the ripening rate of vegetables and fruits, extending the shelf life of these products (Lung and others 2015). Hong and others (2014) evaluated the possibility of using this technology in fruit juice processing. These authors found that a 0.7 kGy irradiation reduced the level of exponential- and stationary-phase cells of *E. coli* by ~4.32 and 3.74 log CFU/mL in apple juice, respectively, whereas starved cells were reduced by only 2.20 log CFU/mL (Hong and others 2014).

Some topics to be addressed include the effect of EBI on enzyme activities, the combination of different technologies to improve the shelf life of food, the standardization of the appropriate dose, the sensory quality of the food, and the effect of EBI on the composition of food (Lung and others 2015).

Inert-Gas Processing

Dense phase carbon dioxide

Dense phase carbon dioxide (DPCD) processing, a collective term for liquid carbon dioxide (LCD) and supercritical carbon dioxide (SCCD–CO_2 above the critical point of 31.1 °C and 7.38 MPa) or high-pressure carbon dioxide (HPCD), is an emerging, non- or mild-thermal preservation method, alternative to high-pressure processing or traditional heating of fruit juices. HPCD near-critical CD and SCCD can be used at temperatures and pressures, which are relatively safe for heat-labile compounds, as well as sufficient for the inactivation of microorganisms and tissue enzymes (Marszałek and others 2015a). The CO_2 used in this process is relatively inert, inexpensive, nontoxic, nonflammable, recyclable, and readily available in high purity, and leaves no residues when removed after the treatment process. Furthermore, it is considered a generally recognized as safe (GRAS) substance, meaning it can be used safely on food products (Cappelletti and others 2015). Table 6 summarizes the different studies on DPCD-assisted treatment applied to fruit and vegetable juices and beverages.

Yuk and Geveke (2011) reported up to 5 log reduction of *Lb. plantarum* in apple cider. In coconut water, Cappelletti and others (2015) found up to 5 log reduction of mesophilic microorganisms, lactic acid bacteria, yeasts, and molds and a 7 log reduction of total coliforms. Guo and others (2011) evaluated the effect of DPCD on litchi juice. These authors obtained 5 log reduction for yeasts and molds and total aerobic microorganisms; the treatment also preserved polyphenols and color, and increased the content of total free amino acids. Recently, Marszałek and others (2017a) studied the effect of different treatment conditions on tissue enzyme inactivation in red beetroot juice.

Microbial inactivation mechanism of DPCD is not yet fully elucidated, although several theories have been proposed. Pataro and others (2014) summarized the steps of the inactivation as follows: (1) solubilization of the pressurized CO_2 in the external liquid phase decreasing the extracellular pH, (2) diffusion of CO_2 through the cell membrane, (3) penetration of CO_2 in the microbial cell and consequent decrease of the intracellular pH, (4) inactivation of the key enzymes and inhibition of cell metabolism due to pH, (5) inhibitory effect of the molecular CO_2 on cell metabolism, (6) disordering of the intracellular electrolyte balance, and (7) removal of vital constituents from the cells and cell membranes.

However, a limited number of reports have dealt with the influence of carbon dioxide on enzymes (Marszałek and others 2017b). The mechanism of enzyme inactivation is hypothesized to be the result of a local decrease of pH. Other researchers suggested that carbon dioxide under pressure could cause changes in the conformation of the secondary structure of the enzymes. Despite these findings, the effect of this technology on the activity and structure of food enzymes is being ivestigated (Marszałek and others 2017b).

Ozonation

Ozone is a powerful antimicrobial substance due to its potential oxidizing capacity. Moreover, the decomposition of ozone to oxygen and the lack of toxic residues make it a favorable environment-friendly sanitizer. Gaseous ozone was recognized as GRAS by the FDA for direct application on food products. Also, gaseous ozone used in food processing is recognized as allowable by organic certification and regulatory bodies (Torlak 2014).

The reason why ozone is widely used in the food industry is that it has many advantages over other treatments. Ozone is a triatomic allotrope of oxygen and decomposes automatically and rapidly to oxygen. It has a high oxidation potential of 2.07 V in alkaline solution compared to that of chlorine (1.36 V), thus it can be used as an effective antimicrobial agent. Also, it can destroy all types of microorganisms at relatively low concentrations. Ozone achieves inactivation of bacteria by having an effect on various cellular components, like proteins, peptidoglycan, enzymes, and nucleic acids in the cytoplasm. Oxidation of unsaturated lipids in the cell envelope causes the leakage of inner contents and finally results in lysis (Sung and others 2014).

With regard to the applications of ozone in the juice industry, a broad range of studies have mainly focused on proving its suitability for obtaining safe products (Table 6). In orange juice, ozonation resulted in 5 log-reduction of *L. monocytogenes* and *L. innocua* (Patil and others 2010). In peach juice, reductions ranged from at least 3.9 to 4.9 log CFU/mL depending on ozone level (10 or 18 ppm) and microorganism, and *L. innocua* is more sensitive than *E. coli*. For *S. cerevisiae*, the treatment was less effective (only 1 log-reduction; Garcia Loredo and others 2015). In another study, the shelf life of apple juice during static storage at 4, 8, 12, and 16 °C was increased when compared with unprocessed control samples (Patil and others 2011).

Recently, Almeida and others (2015) evaluated the effect of ozone processing on the quality of orange juice containing prebiotic oligosaccharides. Ozonation promoted a partial degradation of the oligosaccharides in the prebiotic orange juice. However, the juice maintained enough amount of oligosaccharides to be classified as a prebiotic food; the phenolic content and antioxidant

Table 6–Inert-gas.

Fruit/vegetable source	Product	Treatment conditions	Key finding(s)	Reference
			Dense-phase carbon dioxide	
Apple	Juice	15 and 35 MPa; 15 min; 35 °C	The lowest decrease in apple aroma compounds (59% esters and 59% aldehydes) in samples treated at 15 MPa. Biocidal activity.	Da Porto and others (2010)
Apple	Cider	7.6 MPa; 20 min; 34 to 42 °C	Up to 5 log reduction of *Lb. plantarum* (ATCC 49445). The extent of sublethal injury in survivors increased as processing temperature increased, however the percent injury dramatically decreased during processing at 42 °C.	Yuk and Geveke (2011)
Carrot	Juice	10 to 30 MPa; 5 to 90 min; 32 to 42 °C	Up to 5 log reduction of *Salmonella* Typhimurium (CGMCC 1.1174). The inactivation effect was enhanced by increasing pressure and temperature.	Liao and others (2010a)
Coconut	Water	8 and 12 MPa; 5 to 60 min; 22 to 45 °C	Up to 5 log reduction of mesophilic microorganisms, lactic acid bacteria, yeasts and molds, and a 7 log reduction of the total coliforms.	Cappelletti and others (2015)
Jujube	Juice	5 to 30 MPa; 0 to 50 min; 25 °C	Microbial inactivation in jujube juice had a positive correlation with pressure and holding time. Low browning degree.	Zong and others (2015)
Kiwifruit	Juice	8 and 10 MPa; 0 to 15 min; 35 °C	Total inactivation of both naturally occurring microorganisms and *S. cerevisiae* (ATCC 9763) strain was obtained after 15 min at 10 MPa. No significant changes in chemicol–physical or in sensorial characteristics between untreated and treated juice.	Spilimbergo and Ciola (2010)
Litchi	Juice	8 MPa; 2 min; 36 °C	5 log reduction of yeasts and molds and total aerobic microorganisms. Preservation of polyphenols and original color. Increase of the total free amino acids.	Guo and others (2011)
Orange	Juice	7.6 MPa; 20 min; 42 °C	Increase in the cloud stability. No changes in pH, soluble solids, titratable acidity and ascorbic acid content. 46.5% PME inactivation.	Yuk and others (2014)
Peach	Juice	8 and 10 MPa; 0 to 15 min; 35 °C	Total inactivation of both naturally occurring microorganisms and *S. cerevisiae* (ATCC 9763) was obtained after 15 min at 10 MPa. No changes in chemical-physical or in sensorial characteristics between untreated and treated juice.	Spilimbergo and Ciola (2010)
Strawberry	Juice	30 and 60 MPa; 30 min; 45 °C	Yeasts and molds were not detected after the treatment, whereas total mesophilic count was ~1.7 log CFU/mL. Pressure caused the total inactivation of PPO, as well as a reduction of 83% and 88% of POD for 30 and 60 MPa.	Marszałek and others (2015a)
			Ozonation	
Apple	Juice	33 to 40 μg/mL; 8 min; 15 to 18 °C	The shelf life during static storage at 4, 8, 12, and 16 °C was increased when compared with unprocessed control samples.	Patil and others (2011)
Orange	Juice	0.098 mg O_3/mL; 0 to 8 min	5 log reduction of *L. monocytogenes* (strains ATCC 7644, NCTC 11994) and *L. innocua* (NCTC 11288) at 5 and 8 min.	Patil and others (2010)
Orange	Juice containing prebiotic oligosaccharides	0.057 to 0.230 mg O_3/mL	The process promoted a partial degradation of the oligosaccharides in the juice. However, the juice maintained an enough amount of oligosaccharides to be classified as a prebiotic food. The phenolic content and antioxidant capacity of the treated samples was also well preserved as the pH and color.	Almeida and others (2015)
Peach	Juice	10 and 18 ppm O_3; 20 °C	Reductions ranged from at least 3.9 to 4.9 log CFU/mL according to ozone level (10 ppm or 18 ppm) and microorganism, being *L. innocua* (ATCC 33090) more sensitive than *E. coli* (ATCC 11229). For *S. cerevisiae* (KE162), the treatment was less effective (only 1 log reduction).	Garcia Loredo and others (2015)
			Pressure change technology (PCT)	
Orange	Juice	25 and 50 MPa; 1.3 or 2.6 min; <40 °C	As compared to freshly squeezed juice, PCT treatment slightly reduced levels of carotenoids, vitamin C and hesperidin by 19%, 5%, and 14%, respectively. POD was completely inactivated, whereas residual PME was ca. 26% to 27%. Total aerobic plate count was reduced by 3.4 log CFU/mL.	Aschoff and others (2016)

capacity of the treated samples are preserved as well as pH and color.

Pressure change technology

Pressure change technology (PCT) has been recently proposed as an innovative approach for the nonthermal inactivation of microorganisms. PCT pressurizes liquid products with an inert gas such as nitrogen, helium, or argon at a maximum pressure of 50 MPa. During the retention time, high amounts of inert gas dissolve and diffuse in the medium, including intracellular microbial liquids, until reaching saturation. Therefore, the pressurized liquid is abruptly released to atmospheric pressure by a relief valve, leading to sudden outgassing. The expanding gas disrupts any compartmentalized structure within the liquid, including plant and microbial cells (Aschoff and others 2016).

Aschoff and others (2016) conducted PCT treatment by pressurizing orange juice and nitrogen at moderately high pressures in a tubular continuous reactor. As compared to freshly squeezed juice, PCT treatment slightly reduced levels of carotenoids, vitamin C, and hesperidin by 19%, 5%, and 14%, respectively. POD was completely inactivated, whereas residual pectin methylesterase (PME) activities amounted to 26% to 27%. Total aerobic plate count was reduced by at least 3.4 log CFU/mL.

Cold Plasma Processing

In recent years, cold plasma has emerged as an effective technology for food decontamination (Surowsky and others 2014). Plasma is a neutral ionized gas, characterized by active particles in permanent interactions, such as photons, electrons, positive and negative ions, atoms, free radicals, and excited or nonexcited molecules. In particular, the electron temperature in nonthermal plasmas can reach up to 10,000 K, whereas the entire gas temperature can be close to the room level, hence the term ''cold plasma'' (Bursać Kovačević and others 2016b).

Various studies have shown that cold plasma is capable of inactivating microorganisms located on a variety of food surfaces, food packaging materials, and process equipment under atmospheric pressure conditions (Surowsky and others 2014). Moreover, cold atmospheric gas phase plasma as nonthermal technology has been investigated intensively for providing both, microbial safety, and phenol stability in fruit juices (Table 7).

Shi and others (2011) reported the effective killing action of a cold plasma against *Staphylococcus aureus*, *E. coli,* and *Candida albicans* inoculated in orange juice. Surowsky and others (2014) investigated cold plasma's ability to inactivate *Citrobacter freundii* in apple juice. Elez Garofulić and others (2015) optimized cold atmospheric gas-phase plasma treatment using a response surface methodology in order to evaluate its effect on anthocyanins and phenolic acids in sour cherry juice; plasma treated sour cherry juice had higher amount of phenolic compounds. Similarly, plasma treatment exerted a positive effect on anthocyanins stability and color change in cloudy pomegranate juice (Bursać Kovačević and others 2016b).

Cold plasma has been also proposed to process a prebiotic juice, although it could promot a partial degradation of oligosaccharides (Almeida and others 2015).

Membrane Processing

Membrane technology is an alternative method that reduces heat-associated loss of nutritional and functional quality (for example, phytochemical properties) and has been successfully applied and introduced for commercial production of liquid foods (Laorko and others 2013). Generally, the types of filtration most commonly used are ultrafiltration (UF) and microfiltration (MF), which correspond to pressure-driven processes capable of separating particles in the approximate size ranges of 1 to 100 μm and 0.1 to 10 μm, respectively. Wide ranges of pore size are being used to in the industry, from 18.000 molecular weight cut-off (MWCO) to 0.2 μm (Echavarría and others 2011). Similarly, various materials such as polysulfones, polypropylene, polyamide, nylon, or cellulose acetate have been employed in membrane configuration for dead-end or cross-flow filtration (Gialleli and others 2016). A summary of recent studies on different membrane processing technologies is given in the Table 8.

Reverse osmosis

Reverse osmosis (RO) or hyperfiltration is a separation technique, which operates at (or slightly above or below) room temperature and can be used to concentrate or purify liquids without a phase change (Echavarría and others 2011). The critical threshold of concentration for RO is 25 to 30 °Brix with a single-stage RO system or 45 to 65 °Brix for standard products obtained by evaporation (Bélafi-Bakó and others 2012). Advances over the last years have shown the possibility to concentrate juices, maintaining their nutritional and sensory characteristics. Some examples include the concentration of grape (Gurak and others 2010), pineapple (Couto and others 2011a), and watermelon (dos Santos Gomes and others 2011) juices.

Unfortunately, the rapid reduction in permeate flux due to fouling and/or concentration polarization hinders the commercial application of RO in juice processing (Echavarría and others 2011). Membrane fouling might be caused by pectin, tannins, proteins, starch, hemicelluloses, and cellulose (Yazdanshenas and others 2010), as well as inorganic and organic compounds, and microbes on the external surface of the membrane and/or within the membrane pores (Echavarría and others 2011).

Forward osmosis

The only force of RO is the osmotic pressure difference between the two solutions that flow in counter-current mode on opposite sides of a permeable membrane. Thus, the main advantages of forward osmosis (FO), compared to both thermal and conventional membrane processing, include low hydraulic pressure, low treatment temperature, low fouling tendency, high solids content processing capability, and easy scale-up (Sant'Anna and others 2012). This technology has been effectively applied to sweet lime (Chanukya and Rastogi 2017) and jaboticaba juices (Sant'Anna and others 2016), as well as beetroot and grape juices (Nayak and others 2011).

Microfiltration

Microfiltration (MF) is one of the most important unit operation in industrial process of various juice and beverages. It has been extensively studied as a method for clarification and microbial removal, as well as to maintain high nutritional and sensory quality of processed products (Zhao and others 2015b). Microporous membranes of different materials, configurations, and MWCOs can be used. The feeding solution is applied in parallel to the membrane surface, and pressure is the primary driving force (Echavarría and others 2011).

In watermelon juice, the lycopene concentration and antioxidant capacity were enhanced by 402.8% and 416.3%, respectively (Gomes and others 2013). In pineapple juice, most of the phytochemical properties and soluble components were retained in

Table 7–Cold plasma.

Fruit/vegetable source	Product	Processing conditions	Key finding(s)	Reference
Apple	Juice	Atmospheric pressure plasma; 6 kV; 1.1 MHz; 0 to 480 s; <27 °C	*Cit. freundii* (isolate no. 0613) was reduced by about 5 log CFU/mL after a plasma exposure for 480 s.	Surowsky and others (2014)
Chokeberry	Juice	Atmospheric pressure plasma jet; 25 kW; 3 and 5 min; ~24 °C	Lower stability of flavonols and anthocyanins, and improved stability of hydroxycinnamic acids.	Bursać Kovačević and others (2016a)
Coconut	Liquid endosperm	Atmospheric pressure plasma jet; 450 and 650 W; 0–25 min; <28 °C	Reduction of the initial counts of *E. coli* O157:H7 and *Salmonella enterica* (4.0 log CFU/mL after 22 to 24 min).	Gabriel and others (2016)
Grape	Juice	Atmospheric pressure plasma; 80 kV; 60 Hz; 1 to 4 min	Treatment of grape juice at 80 kV for 4 min resulted in a 7.4 log reduction in *S. cerevisiae* without any significant change in pH, acidity and electrical conductivity of the juice. An increase in nonenzymatic browning was observed, but total color difference was very low and within acceptable limits.	Pankaj and others (2017)
Orange	Juice	Dielectric barrier discharge; 20 kW; 60 kHz; 3 to 12 s and 5 to 25 s; ~20 °C	The numbers of *S. aureus* (ATCC6538), *E. coli* (ATCC8039), or *C. albicans* (ATCC 10231) were below the detection limit within 12, 8, and 25 s, respectively, indicating that more than 5 logs of microorganisms were inactivated. Preservation of the overall quality.	Shi and others (2011)
Orange	Juice containing prebiotic oligosaccharides	Atmospheric pressure plasma; 70 kV; 50 Hz; 15 to 60 s	The process promoted a partial degradation of the oligosaccharides in the juice. However, the juice maintained an enough amount of oligosaccharides to be classified as a prebiotic food. The phenolic content and antioxidant capacity of the treated samples was also well preserved as well as pH and color.	Almeida and others (2015)
Pomegranate	Juice	Atmospheric plasma jet; 2.5 kV; 25 kHz; 3 to 7 min	Plasma treatment had positive influences on anthocyanins stability and color change. The greatest anthocyanin stability was found at 3 min treatment time.	Bursać Kovačević and others (2016b)
Sour cherry	Juice	Atmospheric plasma jet; 2.5 kV; 25 kHz; 3 to 5 min	Short treatment (3 min) resulted in the highest concentration of both anthocyanins and phenolic acids.	Elez Garofulić and others (2015)
Tomato	Juice	Dielectric barrier discharge; 10 kV; 5 min; 30 °C	Cold plasma has less effect on volatile chemical compositions of tomato juice than heat processes. The contents of trans-2-hexenal and *n*-hexanal were significantly higher.	Ma and Lan (2015)

Table 8–Membrane processing.

Fruit/vegetable source(s)	Product	Operating conditions	Key finding(s)	Reference
		Reverse osmosis		
Apple	Juice	Polyamide thin-film composite membrane 2.6 m^2; 25 to 35 bars; 20 and 40 °C	Antioxidant capacity was increased by 40%.	Gunathilake and others (2014)
Black currant	Juice	Thin film composite tubular membrane 0.9 m^2; 45 bar; 30 °C	The total soluble solid content of the juice increased from 17.6 to 17.9 °Brix to 24 to 24.8 °Brix	Pap and others (2010)
Blueberry	Juice	Polyamide thin-film composite membrane 2.6 m^2; 25 to 35 bars; 20 and 40 °C	Antioxidant capacity was increased by 34%. LDL oxidation inhibition increased up to 41%.	Gunathilake and others (2014)
Chokeberry	Juice	Polyamide thin-film composite membranes 0.1736 m^2; 45 to 55 bar; <60 °C	Juice was concentrated till 24.9% of total soluble solids content. Processes at 50 and 55 bar with cooling were the best in terms of chokeberry aroma, antioxidant activity and total phenolic compounds retention.	Pozderović and others (2016)
Cranberry	Juice	Polyamide thin-film composite membrane 2.6 m^2; 25 3o 5 bars; 20 and 40 °C	Antioxidant capacity was increased by 30%. LDL oxidation inhibition was increased up to 45%.	Gunathilake and others (2014)
Grape	Juice	Thin film composite membrane 0.68 m^2; 60 or 40 to 60 bar; 20 to 40 or 40 to 50 °C	The total soluble solid content of the juice increased up to 28.5 °Brix. The increase in total titrable acidity, anthocyanin and phenolic compound contents, color density, and color index proportional to the volumetric concentration factor.	Gurak and others (2010)
Pineapple	Juice	Polyamide composite membrane 0.65 m^2; 20 to 60 bar; 20 to 40 °C	The total soluble solid content of the juice increased up to 31 °Brix when processed at 60 bar and 20°C. These processing conditions were also the consumers' preferred conditions.	Couto and others (2011a)
Watermelon	Juice	Polyamide composite membrane 0.72 m^2; 60 bar; 25 °C	Increase in the physico-chemical properties of the concentrated juice, mainly, in the lycopene and in the antioxidant capacity.	dos Santos Gomes and others (2011)
		Forward osmosis		
Beetroot	Juice	Cellulose triacetate membrane 50 to 100 μm	Total soluble solids increased from 2.3 to 52 °Brix.	Nayak and others (2011)
Grape	Juice	Cellulose triacetate membrane 50 to 100 μm	Total soluble solids increased from 8.0 to 54.6 °Brix.	Nayak and others (2011)
Jaboticaba	Juice	Cellulose triacetate membrane 30 to 50 μm, 1.9×10^{-3} m^2	Forward osmosis preserved anthocyanin content and its antioxidant properties.	Sant'Anna and others (2016)
Pineapple	Juice	Cellulose triacetate membrane 50 to 100 μm	Total soluble solids increased from 4.4 to 54 °Brix.	Nayak and others (2011)
Sweetlime	Juice	A thin and dense semi-permeable skin layer made of cellulose triacetate embedded in a nylon mesh 50 to 100 μm; ~27 °C	2.42-fold concentration.	Chanukya and Rastogi (2017)
Tomato	Juice	Thin film composite polyamide membrane 260 μm	Fresh tomato juice was concentrated from 5.5 °Brix to 16 °Brix, and from 4.25 to 7.5 °Brix.	Petrotos and others (2010)
		Microfiltration		
Apple	Cider	Tubular ceramic membrane 0.2 to 1.4 μm, 0.35 m^2; 159 kPa; ~6 °C	Filtration did not cause any significant changes in pH and soluble solids, regardless of pore size. Viscosity was lower.	Zhao and others (2015b)
Banana	Juice	Polyacrylonitrile polymer 250000 Da, 0.2 μm; 25 °C	Low viscosity and alcohol insoluble solids, and high clarity.	Sagu and others (2014a)
Beetroot	Juice	Mixed cellulose ester membrane 0.45 μm; 0.1 to 1 bar	Decrease of turbidity, as well as total phenolic contents, total soluble solid and juice color. Reduction of the antioxidant value, betacyanin and betaxanthin contents.	Amirasgari and Mirsaeedghazi (2014)
Black mulberry	Juice	Mixed cellulose ester flat membranes 0.22 and 0.1 μm; 0.5 to 200 kPa	Fouling resistance increased with increasing pore size. The increase in pressure increased the membrane fouling resistance.	Hojjatpanah and others (2011)
Bottle gourd	Juice	Hollow fibers membrane 31 cm^2; 13.8 to 158.6 kPa	Enhanced clarity (97%), but lower polyphenol concentration.	Biswas and others (2016)

(*Continued*)

Table 8–Continued.

Fruit/vegetable source(s)	Product	Operating conditions	Key finding(s)	Reference
Carrot	Juice	Multitubular membrane 0.056 m^2, 0.2 μm; 25 °C	Color of juice is better after MF process with a decrease in total solids.	Ennouri and others (2015)
Grape	Juice	Tubular ceramic membranes 0.1 and 0.2 μm; 1 to 3 bar; 30 and 40 °C	An improvement on the permeate flux value was achieved when low pressure and small pore size were used.	Campos and others (2016)
Kiwifruit	Juice	Fly-ash-based membrane 0.30 to 2.13 μm; 150 kPa	Significant improvements in juice color, clarity, and suspended solid contents. A membrane of pore diameter 1.25 μm proved to be optimal for the clarification of kiwifruit juice	Qin and others (2015)
Lemon	Juice	VDF/PMMA/PVP/DMF membranes 0.23 and 0.25 μm; 0.4 to 1 bar; 20 °C	The clarified lemon juice showed physical, chemical, and nutritional characteristics similar to the fresh lemon juice.	Firmán and others (2014)
Orange	Juice	Ceramic membrane 1.66 $\times$ 10^{-3} m; 137.9 to 344.7 kPa	Significant improvement in juice color, clarity and alcohol insoluble solid. Total soluble solid, pH, acidity, and density were unaffected.	Nandi and others (2012)
Passion fruit	Juice	Hollow fibre membrane 0.056 m^2, 0.40 μm; 1 bar	The MF process was able to reduce color and turbidity of the fed juice, resulting in a visually clean product.	Domingues and others (2014)
Pineapple	Juice	Polysulfone hollow fiber membrane 0.011 m^2; 0.2 μm, 1.0 bar; ~20 °C	Most of the phytochemical properties and soluble components were retained in the juice after MF. No microbial growth was detected after 6 mo of storage at 4, 27, and 37 °C.	Laorko and others (2013)
Pomegranate	Juice	Polysulfone membrane 1.8 m^2; 0.2 μm, 2 bar; 30 °C	MF-clarified juice had physicochemical and nutritional properties similar to those of fresh juice. Reverse osmosis as a potential technique to improve antioxidant properties of fruit juices used for functional beverages.	Valero and others (2014)
Prickly pear	Juice	Polyvinylidenfluoride flat sheet membrane 0.20 μm; 140 to 230 kPa; 20 °C or 200 kPa at 20 to 35 °C or 220 kPa at 25 °C.	The investigated model can be utilized for efficient design of gel layer controlling membrane filtration in radial cross flow cell and subsequent scaling up.	Mondal and others (2014)
Red plum	Juice	Hydrophilic PVDF flat membrane 0.22 μm or MCE flat membranes 0.025 to 0.25 μm, 0.0209 m^2; 0.5 to 2.9 bar; 20 to 40 °C	The clarification of juice reduces its turbidity and removes suspended solids. Increasing the temperature from 30 to 40 °C was the most effective factor in decreasing cake-layer fouling, reducing it by about 66.7%.	Nourbakhsh and others (2014)
Red raspberry	Juice	Ceramic membrane 0.2 μm; 0.5 to 3 bar; 22 to 55 °C	A minimal loss of anthocyanins (from 630 to 540 mg/L). Light transmission at 625 nm in permeate was above 85% and the residual pectin (900 mg/L) was completely removed.	Vladisavljević and others (2013)
Sour orange	Juice	Mixed cellulose esters 0.45 μm, 0.0216 m^2; 0.3 to 0.9 bar	Although membrane clarification decreased turbidity, acidity, ascorbic acid and total soluble solid content of bitter orange juice; its polyphenol components and antioxidant activity did not change. MF eliminates more than 90% of the particles in bitter orange juice and preserves its main nutritional compounds successfully.	Mirsaeedghazi and Emam-Djomeh (2017)
Sugarcane	Juice	Polyamide hollow-fiber membrane 0.4 μm, 0.723 m^2; 1.32 to 4.68 bar; 13.2 to 46.6 °C	In the clarified juice there was a reduction in the contents of total solids, proteins, vitamin C, and acidity, whereas the soluble solids, pH, and ash contents did not change.	Rezzadori and others (2014)
Tomato	Juice	PVDF membrane 0.45 μm, 41.25 m^2; 1 to 3 bar; ~50 °C	MF results in a clear permeate juice retaining almost the total amount of soluble solids and citric acid present in the feed.	Razi and others (2012)
Watermelon	Juice	Ceramic membrane 0.1 μm, 0.022 m^2; 3.0 bar; 23 to 37 °C	The lycopene concentration and antioxidant capacity were enhanced up to 402.8% and 416.3%, respectively.	Gomes and others (2013)
			Ultrafiltration	
Acerola	Juice	Polyethersulfone membranes 5 to 20 psi, 50 cm^2; 5 to 300 kDa; room temperature	The best UF condition (300 kDa at 15 psi of transmembrane pressure) resulted in the biggest permeate flux, with the lowest fouling and excellent nutritional quality of the permeate.	Milani and others (2015)
Apple	Juice	PVDF membrane 0.116 m^2; 18 kDa; ~2.5 bar; ~50 °C	The permeation flux during the first 5 h of operation was controlled by fouling and afterward the concentration polarization predicted the flux.	Yazdanshenas and others (2010)

(*Continued*)

Table 8–Continued.

Fruit/vegetable source(s)	Product	Operating conditions	Key finding(s)	Reference
Black currant	Juice	Polyethersulfone membrane 0.1 m^2; 100 kDa; 2 bars; 25 °C	No effect on the total soluble solid content and pH of the juices. However, it had a significant effect on the valuable compound content; 50% and 54% of total anthocyanins and the total flavonol content maintained, respectively, in the permeate compared to initial juice.	Pap and others (2012)
Black mulberry	Juice	Mixed cellulose ester flat membranes 0.025 μm	Intermediate blocking was the dominant fouling mechanism.	Hojjatpanah and others (2011)
Beetroot	Juice	Polyethersulfone membrane 10 to 150 kDa; 2 bars; 20 °C	The purity of juice was increased from ~ 93% to 96% with a 10 kDa membrane.	Zhu and others (2015)
Blackberry	Juice	Thin film, polyethersulphone or permanently hydrophilic polyethersulphone membranes 0.0155 m^2; 1 to 150 kDa; 0.5 to 3 MPa; 30 °C.	Retention of total anthocyanins increased with transmembrane pressure and reached values over 90% for all membranes tested at 3 MPa.	Acosta and others (2014)
Coconut	Water	Thin film composite polyamide membrane 35.26 cm^2; 276 to 690 kPa; 50 kDa	Effect on color and clarity.	Jayanti and others (2010)
Cucumber	Juice	Ceramic membrane 0.05 μm, 0.1 m^2; 0.3 MPa; 25 °C	UF significantly decreased total aerobic bacteria and yeasts and molds in the juice by ~1.35 and 1.94 log CFU/mL, respectively, increased juice clarity to ~99.85, and did not change pH, titrable acidity and four key aroma compounds of (*Z*)-6-nonenal, (*E*,*Z*)-2,6-nonadienal, (*E*)-2-nonenal, and (*E*,*Z*)-3,6- nonadien-1-ol.	Liu and others (2016)
Grape	Juice	Tubular ceramic membranes 0.05 μm; 1 to 3 bar; 30 and 40 °C	High permeate flux value and suitable grape juice characteristics were attained using 1 bar pressure at 40 °C.	Campos and others (2016)
Lemon	Juice	VDF/PMMA/PVP/DMF membranes 0.015 μm; 0.4 to 1 bar; 20 °C	The clarified lemon juice presented physical, chemical, and nutritional characteristics similar to the fresh lemon juice.	Firmán and others (2014)
Orange	Juice	Stainless steel membrane 276 to 552 kPa	The leftover pectin in the juice had the major contribution in the flux reduction during filtration.	Rai and others (2010)
Pear	Juice	Ceramic membrane 0.05 μm, 0.1 m^2; 0.3 MPa; 25 °C	3.05 and 3.36 log reduction of total plate count and yeasts and molds, respectively. Total phenols and ascorbic acid were decreased by 25.74% and 37.48%, respectively.	Zhao and others (2016)
Pomegranate	Juice	Stainless steel membrane 75 cm^2; 15 kDa; 1 to 4 bar; 20 °C	The initial color of the raw pomegranate juice was reduced from 74% to 33% and the clarity decreased from 77% to 42% by UF when the transmembrane pressure increased from (1 to 3.6) bar. Total phenolic rejection decreased from 45% to 21% when the transmembrane pressure rose from (1 to 2) bar and remained constant above this value.	Baklouti and others (2012)
Prickly pear	Juice	PVDF flat sheet membrane 0.20 μm, 11.33 cm^2; 200 kDa; 2.2 bar; ~25 °C	Total soluble solids, pH and acidity remained unchanged in the clarified juice. On the contrary, suspended solids were completely removed.	Cassano and others (2010)
Red raspberry	Juice	Ceramic or polysulfone membranes 1.8 m^2; 1 bar; 30 to 300 kDa; 22 °C.	The content of anthocyanins was reduced to 220 to 370 mg/L, but a light transmission at 625 nm was as high as 96%.	Vladisavljević and others (2013)
			Nanofiltration	
Apple	Juice	Nano-tubular cellulose filters (1348 and 1733 cm^3)	The system was effective for treatment of commercial juice contaminated by *S. cerevisiae* (AXAZ-1) and *Lb. plantarum* (DSM 20174) cells. The increased size of the filter improved the operational stability of the continuous process and favored scale-up. The composition and sensory characteristics of the juice were affected at the beginning of the process and after each filter regeneration but as soon the process proceeded the initial composition levels were reached.	Gialleli and others (2016)

(*Continued*)

Table 8–Continued.

Fruit/vegetable source(s)	Product	Operating conditions	Key finding(s)	Reference
Pear	Juice	Spiral wound composite polyamide membrane 0.353 m^2; 5000 kDa; ~1240 kPa; 50 °C	Significant increase in lightness, improvement from brownish tinge to clear light greenish tinge and an improvement in overall color difference values. No significant changes in the pH values. Minor reduction in the titratable acidity.	Vivekanand and others (2012)
Watermelon	Juice	Polyvinylidene difluoride (PVDF) membranes 0.6 m^2; 150 to 300 Da; 600 kPa; ~25 °C	An increase in the antioxidant activity of the concentrate samples with the increase in the volume reduction factor was observed. Moreover, the contents of flavonoids, phenolic compounds, ascorbic acid and lycopene in the watermelon juice were highly significantly correlated with the antioxidant potential of the samples.	Arriola and others (2014)
			Membrane distillation	
Aloe vera	Juice	Stainless steel membrane 0.2 μm, 0.0015 m^2; 40 to 70 °C	Polysaccharide retention was greater than 68%. Transmembrane flux gradually increases with increase of feed juice temperature at constant flow rate and constant permeate temperature.	Dershmukh and others (2013)
Tomato	Juice	Polypropylene membrane 0.1 m^2, 0.2 μm	Ascorbic acid and dehydroascorbic acid levels were decreased significantly after processing. Sensorial evaluation also showed that, except consistence, products obtained by membrane technique gained higher scores than thermally concentrated product.	Savaş Bahçeci and others (2015)
			Osmotic distillation	
Apple	Juice	PTFE hydrophobic polymeric membrane 0.20 and 0.45 μm or PVDF 0.45 μm or PP 0.10 μm / 1.20×10^{-3} m^2; 20 °C.	No loss of polyphenol content or reduction of antioxidant activity.	Kujawa and others (2015)
Beetroot	Juice	PTFE hydrophobic polymeric membrane 0.20 and 0.45 μm or PVDF 0.45 μm or PP 0.10 μm / 1.20×10^{-3} m^2; 20 °C.	No loss of polyphenol content or reduction of antioxidant activity.	Kujawa and others (2015)
Blackthorn	Juice	Polypropylene capillary membrane 0.2 μm 150 cm^2; 45 kDa; 17 to 30 °C	The total soluble solid content of the juice increased up to 60 °Brix. Both the antioxidant capacity and the total polyphenol content were almost completely preserved.	Bélafi-Bakó and others (2012)
Common whitebeam	Juice	Polypropylene capillary membrane 0.2 μm 150 cm^2; 45 kDa; 17 to 30 °C	The total soluble solid content of the juice increased up to 60 °Brix. Both the antioxidant capacity and the total polyphenol content were almost completely preserved.	Bélafi-Bakó and others (2012)
Cornelian cherry	Juice	Polypropylene capillary membrane 0.2 μm 150 cm^2; 45 kDa; 17 to 30 °C	The total soluble solid content of the juice increased up to 60 °Brix. Both the antioxidant capacity and the total polyphenol content were almost completely preserved.	Bélafi-Bakó and others (2012)
Cranberry	Juice	Polypropylene hollow fiber membrane 0.580 m^2; 30 to 40 °C.	The concentration of cranberry juice by OD does not affect the content of phenolic compounds and specifically of anthocyanins.	Zambra and others (2015)
Grape	Juice	Hydrophobic, polypropylene, hollow-fiber membrane 0.2 μm, 10.2 m^2	The physico-chemical properties of juice were not significantly modified.	Cissé and others (2011)
Tomato	Juice	Polypropylene membrane 0.1 m^2, 0.2 μm	Ascorbic acid and dehydroascorbic acid levels were reduced.	Savaş Bahçeci and others (2015)

the juice after MF; in addition, no microbial growth was detected after 6 mo of storage at 4, 27, and 37° C (Laorko and others 2013). Significant improvements in the overall quality of clarified products have been also reported for carrot (Ennouri and others 2015), kiwifruit (Qin and others 2015), orange (Nandi and others 2012), and pomegranate (Valero and others 2014) juices.

However, MF clarification process can lead to decrease of some physicochemical properties of red beet juice such as antioxidant activity, betacyanins, betaxanthins, and total phenolic compounds (Amirasgari and Mirsaeedghazi 2014).

Ultrafiltration

Ultrafiltration (UF) membrane is able to retain large particles such as microorganism, lipids, protein, and colloids; the small particles, for example vitamins, salts, and sugars, are well preserved in juice. Compared to traditional filtration, UF is more efficient and requires shorter processing time, can avoid the use of fining agents (clarification) and high temperatures (concentration; Zhao and others 2016).

In black currant juice, UF had no significant effect on the total soluble solid content and pH of the juices. However, it had a significant effect on the valuable compound content; 50% and 54% of total anthocyanins and the total flavonol were found in the permeate compared to initial juice (Pap and others 2012). In pear juice, UF decreased total phenols and ascorbic acid by 25.74% and 37.48%, respectively; in addition, 3.05 and 3.36 log reduction of total plate count and yeasts and molds were found, respectively (Zhao and others 2016).

The major problem with the membrane filtration is the permeate flux decline during the operation that affects directly the economy of the process (Pap and others 2012). Hence, enzymatic treatment for depectinization is recommended, as pectin particles present in the juice can cause the fouling of the membranes (Pap and others 2012).

Nanofiltration

Nanofiltration (NF) is a pressure-driven membrane process for liquid-phase separation and its properties lies between those of nonporous RO membranes and porous UF membranes. The application of NF for concentration of fruit or vegetable juices and extracts is also advantageous in terms of cost, because the process is less energy-consuming than RO (Acosta and others 2017). NF has been used as one of the steps in the clarification and concentration of raw juice as well as in the processing of nonsugar compounds (Echavarría and others 2011).

Vivekanand and others (2012) found that NF led a significant increase in lightness on pear juice, as well as an improvement from brownish tinge to clear light greenish tinge and an improvement in overall color difference values. Arriola and others (2014) observed an increase in the antioxidant activity of the concentrate samples with the increase in the volume reduction factor.

The problems associated with NF include low flux rate, high rejection of sugars, and requirement of a large membrane surface area. These problems have largely contributed to its limited application on a commercial scale (Vivekanand and others 2012).

Recently, a different system was proposed by Gialleli and others (2016). This system involves the use of a porous cellulosic material (tubular cellulose), containing nano/micro-pores and tubes produced after wood sawdust delignification. The system was effective for treatment of commercial apple juice contaminated by bacteria and yeast cells.

Membrane distillation

Membrane distillation (MD) as a separation process involves the transport of water vapor through the pores of hydrophobic membranes, where the driving force is the vapor pressure difference created by the temperature difference across the membrane. MD can be carried out at atmospheric pressure and temperature, thus it can be used to concentrate solutes sensitive to high temperature (Savaş Bahçeci and others 2015). MD has many benefits, such as high system compactness, the simplicity of the membrane, larger pores than of RO membranes (and typically larger than in UF membranes), not affected by fouling (Dershmukh and others 2013).

Savaş Bahçeci and others (2015) evaluated the effects of MD on tomato juice. The sensorial evaluation showed that the products gained higher scores than thermally concentrated product; however, ascorbic acid and dehydroascorbic acid levels were significantly decreased after processing. Dershmukh and others (2013) found a polysaccharide retention of 68%.

Osmotic distillation

The same membrane modules used in MD can also be employed in osmotic distillation (OD). The difference between MD and OD is the way to generate the driving force. In OD the vapor pressure gradient results from a concentration gradient to the permeate side of the membrane, generated using an extracting solution on the permeate side of the module (Savaş Bahçeci and others 2015). The principal benefit of OD lies in its ability to concentrate solutes to very high levels (to as much as 65 °Brix) at low pressure and temperature, with minimal mechanical or thermal damage or loss of the solutes (Cissé and others 2011; Kujawa and others 2015).

Kujawa and others (2015) reported no loss of polyphenol content or reduction of antioxidant activity after the dehydration of apple and beetroot juices. Bélafi-Bakó and others (2012) found that around 60 °Brix was achieved by the process and both the antioxidant capacity and the total polyphenol content of blackthorn, common whitebeam and cornelian cherry juices were almost completely preserved. OD process does not affect the content of phenolic compounds and specifically of anthocyanins in cranberry juice (Zambra and others 2015), as well as the chemical properties of grape juice (Cissé and others 2011).

Improving the Effectiveness of Nonthermal Processing

Some nonthermal techniques when used individually might not be effective and require the use of combined treatments, which is expected to provide synergistic effects. Different approaches have been proposed including: (1) the evaluation of intrinsic hurdles such as pH and dissolved solids (°Brix), (2) the combination with heat or the application of heat before or after nonthermal processes, as well as (3) the use of combined technologies and (4) the combination with other preservation tools such as antimicrobials and bacteriocins. An overview of different approaches currently used to improve effectiveness of nonthermal processing technologies is reported in Tables 9 to 14.

Evaluation of intrinsic hurdles

The evaluation of solids content is of great concern. Sokołowska and others (2013a) evaluated the baroprotective effect of increased solute concentration in apple juice on *Al. acidoterrestris* (strains TO-29/4/02 and TO-117/02) spores during HHP processing. During the pressurization of 71.1 °Brix concentrated juice, there were no significant changes in their number. However, in the juices whose soluble solids content was 35.7, 23.6, and 11.2 °Brix,

Table 9–Improving the effectiveness of nonthermal treatments—approach 1: evaluation of intrinsic hurdles.

Fruit/vegetable source(s)	Product	Processing conditions	Intrinsic hurdle	Key finding(s)	Reference
			High hydrostatic pressure		
Aloe vera	Juice	60 to 740 MPa; 3 to 30 min; ~25 °C	pH 2.32 to 5.68	Reduction of the naturally occurring microbiota by 5.66 log CFU/mL at 400 MPa/20 min at pH 4.	Swami Hulle and others (2015)
Apple	Juice	200 MPa; 0 to 45 min; 50 °C	Soluble solids 11.2 to 71.1 °Brix	During the pressurization of *Al. acidoterrestris* (strains TO-29/4/02 and TO-117/02) in concentrated apple juice (71.1 °Brix), there were no significant changes in their number. However, in the juices whose soluble solids content was 35.7, 23.6, and 11.2°C Brix, spore reduction was 2.4, 3.3,and 4.0 log CFU/mL, respectively for TO-29/4/02 strain, and 1.3, 2.6, and 2.8 log CFU/mL, respectively, for TO-117/02 strain.	Sokołowska and others (2013a)
Carrot	Juice	400 to 600 MPa; 0 to 40 min; 40 to 60 °C	pH 4.5 and 5.5	A 5 log reduction in *B. licheniformis* spores was observed after HHP treatment of 3 min at 600 MPa, 60 °C at pH 4.5.	Tola and Ramaswamy (2014)
Grape	Wine	100 MPa; 24 h; 25 °C	pH 3.2 and 3.6	No effect on *Dekkera bruxellensis* (strain D37).	Morata and others (2012)
Tomato	Juice	600 MPa; 1 min; ~16 °C	pH 3.9 and 4.3	Total viable count <2 log CFU/mL, irrespective of pH. Tomato juice with natural pH (4.3) showed significant red color retention compared to the juice with the pH altered (3.9).	Jayathunge and others (2015)
			High-pressure homogenization		
Mandarin	Juice	150 MPa; 10 s; 58 to 68 °C	pH 3.1 to 3.9	Samples with pH 3.1 and homogenized at 68 °C showed a residual PME <10%.	Navarro and others (2014)
Orange	Juice	150 MPa; 10 s; 58 to 68 °C	pH 3.1 to 3.9	Samples with pH 3.1 and homogenized at 68 °C showed a residual PME <10%.	Navarro and others (2014)
			Sonication		
Carrot	Juice	300 W; 21 kHz; 30 min	Soluble solids 9 to 21 °Brix	Application of US caused a significant decrease in freezing time for shock convective freezing only in juices at a concentration of 12 and 21 °Brix.	Janiszewska and Sakowski (2013)
			Gamma radiation		
Apple	Concentrated juice	1 to 10 kGy	Soluble solids 18 to 72 °Brix	When 10 kGy was applied to juice, populations of *Al. acidoterrestris* spores were reduced by 4.34, 3.9, and 3.84 log CFU/mL in 18, 36, and 72 °Brix apple juice concentrates, respectively.	Lee and others (2014)
Orange	Concentrated juice	1 to 10 kGy	Soluble solids 11 to 66 °Brix	When 10 kGy was applied to 11 °Brix orange juice, populations of *Al. acidoterrestris* spores were reduced by 5 log. The reduction of spores in 33 and 66 °Brix orange juice concentrates exposed to 10 kGy gamma irradiation was 4.54 and 3.85 log CFU/mL, respectively.	Lee and others (2014)
			Ozonation		
Apple	Juice	2.0 to 3.0 g O_3/m^3; 1 to 4 min; 22 °C	pH 3.0 to 5.0	Ozone treatment (4 min) of pH 3.0 apple juice resulted in >5.36 log reduction of *E. coli* O157:H7. Ozone treatment of pH 4.0 and 5.0 apple juice for 4 min reduced this pathogen by 5.12 and 1.86 log CFU/mL, respectively.	Song and others (2015a)
Apple	Juice	2.0 to 3.0 g O_3/m^3; 20–60 s; 25 to 55 °C	Soluble solids 18 to 72 °Brix	Reduction of *E. coli* O157:H7 and *Salmonella* Typhimurium to below the detection limit after 1 min treatment in 72 °Brix apple juice. Ozone combined with heat shows synergistic effect on *E. coli* O157:H7 and *S.* Typhimurium in 18 and 36 °Brix, but not in 72 °Brix apple juice.	Song and others (2015b)
			Dense phase carbon dioxide		
Apple	Juice	60 MPa; 20 to 40 min; 50 and 75 °C	Soluble solids 11.2 to 70.7 °Brix	A high level of soluble solids prevented the germination of *Al. acidoterrestris* spores. For example, after 40 min of treatment at 75 °C, germination of *Al. acidoterrestris* TO-24 169/06 spores in apple juice (11.2 °Bx) was 3.9 log CFU/mL of which 3.4 log CFU/mL were inactivated. Under the same process conditions, in 70.7 °Brix juice much lower degree of germination (0.9 log CFU/mL) and inactivation (0.5 log CFU/mL) was obtained.	Porębska and others (2017)
			Osmotic distillation		
Grape	Juice	PTFE hydrophobic membranes; 0.2 to 1.2 μm; ~35 °C	Soluble solids 5 to 20 °Brix	Preservation of the physicochemical properties of juice. However, the antioxidant capacity increased linearly with the red grape juice concentration.	Kujawski and others (2013)

Table 10–Improving the effectiveness of nonthermal treatments—Approach 2: combination with heat.

Fruit/vegetable source(s)	Product	Processing conditions	Process temperature(s)	Key finding(s)	Reference
			PULSED ELECTRIC FIELDS		
Apple	Juice	20 to 30 kV; 6 to 123 μs	<60 °C	The inactivation of *E. coli* O157:H7 treated in apple juice ranged from 0.4 to 3.6 log CFU/mL.	Saldaña and others (2011)
Apple, banana, coconut, orange, pineapple	Smoothie	25 Hz; 34 kV/cm; 1 μs; 60 μs	55 °C	Microbiological shelf life of 28 d at 4 °C.	Walkling-Ribeiro and others (2010)
Apple, banana, strawberry	Smoothie	0 to 24 kV/cm	<58 to 59 °C	The application of PEF treatment (partly) inactivates the yeasts, providing outgrowth opportunities for molds, which lead to spoilage after 14 ds (7 °C) or 18 d (4 °C). Outgrowth of yeast after PEF treatment was affected by electrical field strength and storage temperature.	Timmermans and others (2016)
Blueberry	Juice	400 Hz; 36 kV/cm; 3 μs; 100 μs	<60 °C	The microbial load is always below the detection limit. Juice showed a decrease lower than 5% in ascorbic acid content. At the end of refrigerated storage, PEF-treated juice showed ascorbic acid losses (50%) in relation to untreated juice.	Barba and others (2012b)
Orange	Juice	25.26 kV/cm; 3 μs; 1206.2 μs	<58.2 °C	93.8% PME inactivation. Enzymatic activity of PEF-processed samples decreased or did not change during 180 d-refrigerated storage. Stable flavonoids and phenolic acids.	Ağçam and others (2014)
Orange	Juice mixed with milk	25 kV/cm; 2.5 μs; 280 μs	57 °C	5 log reduction of *Lb. plantarum* (CECT 220). Low nonenzymatic browning.	Zulueta and others (2013)
Pomegranate	Juice	35 and 38 kV/cm; 281 μs	55 °C	PEF treatments significantly inhibited the growth of total aerobic bacteria, which remained at <2.5 log CFU/mL for 12 wk storage. Yeasts and molds were not detected in the PEF-treated juices during storage up to weeks 10 and 12.	Guo and others (2014)
Red-fleshed apple	Juice	200 Hz; 10 to 30 kV/cm; 2 μs; 200 to 1000 μs	20 to 60 °C	Treatments conducted at 30 kV/cm, 1000 μs and 60 °C led to red apple juice with the lowest residual enzyme activity (0.04 and 0.16 for PPO and POD, respectively).	Katiyo and others (2014)
Strawberry	Juice	18.6 kV/cm; 2.6 μs; 150 μs	45 to 55 °C	Inactivation of nonpathogenic *E. coli* (ATCC 35218) at 45, 50, and 55 °C (2.86, 3.12, and 3.79 log CFU/mL).	Gurtler and others (2011)
Tomato	Juice	5.5 and 6.7 kV/cm	65.3 °C	Residual *L. innocua*, *E. coli*, *Lb. plantarum*, *S. cerevisiae* and *A. niger* were below the detection limit for at least 21 ds. Increase of *dl*-limonene, *E*-citral and *Z*-citral contents.	Aganovic and others (2014)
Twistspine pricklypear	Juice	35 kV/cm; 3 μs	<67 °C	PEF produced juice with the same inactivation effect on the microorganisms found in the thermally pasteurized juice (gentle impact on physicochemical and rheological properties. High degree of retention for sensitive bioactive compounds and the antioxidant activity of the fresh juice).	Moussa-Ayoub and others (2017)
Watermelon	Juice	11 kV/cm;20 μs	<72 °C	*E. coli*, *L. innocua*, *Lb. plantarum* and *S. cerevisiae* were inactivated to levels below the detection limit. PEF could be alternative to pasteurization for reducing formation of Maillard and Strecker degradation products.	Aganovic and others (2016)
			Radio-frequency electric fields		
Apple	Juice	25 kV/cm; 20 kHz; 3.4 ms	25 to 75 °C	At 75 °C the viability loss for *E. coli* K-12 (ATCC 23716) was 7 log CFU/mL.	Ukuku and others (2012)
			High hydrostatic pressure		
Aloe vera, litchi	Mixed beverage	600 MPa; 15 min	56 °C	Inactivation of PME, PPO, and POD to 34%, 65%, and 62%, respectively. The ascorbic acid loss of up to 22%. The shelf life of treated samples stored at 4 °C was 100 d.	Swami Hulle and Rao (2016)
Apple	Juice	600 MPa; 0 to 40 min	50 to 75 °C	HHP-75 °C was the most effective technique for inactivating *N. fischeri* (JCM 1740) ascospores, resulting in 3.3 log reduction after 10 min.	Evelyn and others (2016)
Blueberry	Juice	100 to 700 MPa; 5 to 300 min	40 to 121 °C	32% degradation of anthocyanins after 20 min heating at 100 °C and atmospheric pressure, whereas at 100 °C and 600 MPa, approximately 50% of total anthocyanins were lost.	Buckow and others (2010)

(*Continued*)

Table 10–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Process temperature(s)	Key finding(s)	Reference
Carrot	Juice	300 to 500 MPa; 15 min	40 to 60 °C	400 to 500 MPa/50 °C and 300 to 500 MPa/60 °C-treated samples had a shelf life of 28 d at 4 °C. 16% to 50% reduction of POD activity. High preservation of ascorbic acid, color (except 500 MPa/60 °C), carotenoids, sensory attributes. At constant pressure, bacterial inactivation increased with increasing temperature.	Gong and others (2015)
Litchi	Juice	200 to 600 MPa; 10 min	20 to 60 °C	The sensory acceptance of high pressure treatment was similar to fresh litchi juice.	Kaushik and others (2015)
Longan, yanang	Honey-based mixed	400 to 600 MPa; 20 min	25 and 50 °C	Total plate counts, yeasts and molds and fecal coliforms in pressurized juices were below the detection limit. The levels of ascorbic acid and antioxidant capacity decreased according to treatment severities.	Chaikham and Prangthip (2015)
Coconut, lemon, litchi	Beverage blend	200 to 600 MPa; 5 to 20 min	50 to 70 °C	Increase in phenolic content (3% to 12%) and total antioxidant capacity (1% to 19%) at 500 and 600 MPa. Adverse effect pressurization at 70 °C on the color.	Jayachandran and others (2015)
Melon	Juice	300 to 500 MPa; 10 to 20 min	45 to 65 °C	The optimum process parameters for a 5 log reduction of *B. subtilis* spores were: pressure = 464 MPa, temperature = 54.61 °C, and holding time = 12.8 min.	Chen and others (2015b)
Orange	Juice	200 to 600 MPa; 10 min	20 to 60 °C	3 log reduction of *Al. acidoterrestris* (DSMZ 2498) at 600 MPa/50°C	Hartyáni and others (2013)
Orange	Comminuted juice	350 and 550 MPa; 1 to 10 min	41 to 68 °C	The lowest residual PME activity value (15.6%) was obtained at 550 MPa/68 °C/10 min	Tejada-Ortigoza and others (2015)
Pineapple	Juice	400 MPa; 20 min	20 to 50 °C	In the case of 400 MPa and 50 °C, the reduction rate of allergenicity was higher, up to 50% compared to that of the sample at 20 °C without high hydrostatic pressure treatment.	Liang and others (2015)
Red raspberry	Juice	400 to 800 MPa; 0 to 25 min	20 and 50 °C	The effect of pressure on the degradation of the bioactive compounds was not significant. Breakdown of anthocyanins and ascorbic acid occurred when temperature increased.	Verbeyst and others (2012)
Strawberry	Juice	400 to 800 MPa; 0 to 25 min	20 and 50 °C	The effect of pressure on the degradation of the bioactive compounds was not significant. Breakdown of anthocyanins and ascorbic acid occurred when temperature increased.	Verbeyst and others (2012)
Strawberry	Nectar	300 and 500 MPa; 5 to 15 min	50 °C	The high pressure applied had a positive effect on the content of anthocyanins immediately after the process; however, the losses of those components during the storage were higher than in the traditionally pasteurized products.	Marszałek and others (2011)
Tomato	Juice	600 MPa; 10 min	75 to 105 °C	*B. coagulans* (185A, 186A, and ATCC 7050) spores seemed to be more sensitive to combined pressure-heat treatment than thermal processing alone (2.3 and 3 times lower *D*-values for pressure-heat inactivation at 100 and 105 °C, respectively as compared to thermal processing).	Daryaei and Balasubramaniam (2013)
Watermelon	Juice	400 MPa; 20 min	30 to 60 °C	The absorption of protein was reduced after the treatment at 30 and 60 °C. The protein structure of watermelon juice changed with the increase of temperature.	Liu and others (2015)
Pulsed-high hydrostatic pressure					
Apple	Juice	300 to 500 MPa; 6 pulses × 50 s and 2 pulses × 150 s	30 to 50 °C	Patulin reduction occurred.	Avsaroglu and others (2015)
High pressure homogenization					
Mango	Juice	40 to 190 MPa	20 to 60 °C	Complete inactivation of molds and yeasts was achieved by 1 and 3 passes at 190 MPa and 60 °C, while total plate count was below 2.0 log CFU/mL.	Guan and others (2016)
Orange	Juice	150 Mpa; 15 s	68 °C	Homogenization at 150 MPa and 68 °C preserved acceptability and cloudiness of juice for at least 3 mo of refrigerated storage at 3 °C even with a high residual PME activity (75%).	Carbonell and others (2013)
Ultra-high-pressure homogenization					
Grape	Juice	200 to 400 Mpa	<74.2 °C	The complete inactivation of *Salmonella enterica* serovar Senftenberg 775W (CECT 4565) was achieved at 400 MPa. *L. monocytogenes* (CCUG 15526) was more resistant. Sublethal injuries were not detected in any case.	Velázquez-Estrada and others (2011)

(*Continued*)

Table 10–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Process temperature(s)	Key finding(s)	Reference
Orange	Juice	300 MPa	20 to 80 °C	Treatment hardly affected spore counts of *Al. acidoterrestris* (CECT 7094) and *Al. hesperidum* (CECT 5324) at the lowest inlet temperature (20 °C), but significant reductions were observed when inlet temperature raised to 60 °C, achieving lethality values above 5 log when juice samples were preheated at 70 °C for *Al. hesperidum* and 80 °C for *Al. acidoterrestris*, respectively.	Roig-Sagués and others (2015)
Strawberry	Juice	205 MPa	20 and 70 °C	UHPH treatment at 70 °C resulted in a longer color retention and higher sugar contents in strawberry juice stored at 4 °C for 63 d.	Won and others (2015)
			Thermosonication		
Apple	Juice	400 W; 120 μm; 24 kHz; 0 to 30 min	50 and 60 °C	6 log reduction of *E. coli* (ATCC 11775) after 5 min at 60 °C.	Moody and others (2014)
Apple	Nectar	600 W; 60 to 120 μm; 20 kHz; 3 to 9 min	20 to 60 °C	Ultrasonic treatment lead to the formation of new compounds (which were not present in the untreated samples) or to the disappearance of some compounds.	Šimunek and others (2013)
Apple	Cider	750 W; 20 kHz; 0 to 4 min	59 °C	A 5 log reduction of *E. coli* K12 was achieved in 3.8 min.	Lee and others (2013a)
Blackberry	Juice	1500 W; 20 kHz; 13 to 27 min	40 to 52 °C	Total inactivation of natural microorganisms. Thermoultrasound highly inactivated both enzymes (PME and PPO) up to 63.71% and 98.28% respectively, in comparison to the pasteurized juice (14.67% and 89.75% respectively).	Cervantes-Elizarrarás and others (2017)
Black mulberry	Juice	750 W; 100%; 20 kHz; 0 to 10 min	30 to 50 °C	The treatment time for 5 log reduction of the *E. coli* (ATCC 25922) was estimated in 10.45 min for TMS at 50°C. Color and turbidity values increased, whereas monomeric anthocyanin contents decreased.	Dinçer and Topuz (2015)
Blueberry	Juice	600 W; 60–120 μm; 20 kHz; 3–9 min	40 and 60 °C	The largest increase in consistency coefficient is observed after ultrasonic treatment at amplitude 120 μm, 6 min treatment time and the sample temperature of 40 °C. The largest decrease in consistency coefficient is observed at amplitude 60 μm, 3 min treatment time and the sample temperature of 60 °C.	Šimunek and others (2014)
Blueberry	Nectar	600 W; 60 to 120 μm; 20 kHz; 3 to 9 min	40 and 60 °C	The largest decrease in consistency coefficient is observed after ultrasonic treatment at amplitude 90 μm, 6 min treatment time and the sample temperature of 40 °C.	Šimunek and others (2014)
Black jamun	Juice	100 W; 30 KHz; 30 min	~50 °C	Increase in total phenolic content and total flavonoid content.	Saikia and others (2015)
Carambola	Juice	100 W; 30 KHz for 30 min	~50 °C	Increase in total phenolic content and total flavonoid content.	Saikia and others (2015)
Carrot	Juice	400 W; 120 μm; 24 kHz; 10 min	50 to 58 °C	Samples sonicated at 58 °C had the best quality; microbial growth remained low at around 3 log CFU/mL for mesophiles, 4.5 log CFU/mL for yeasts and molds, and 2 log CFU/mL for enterobacteria after 20 d of storage at 4 °C. Furthermore, thermo-sonicated juice at 58 °C retained >98% of carotenoids and 100% of ascorbic acid.	Martínez-Flores and others (2015)
Cranberry	Juice	400 W; 120 μm; 24 kHz; 0 to 10 min	40 to 60 °C	*S. cerevisiae* (ATCC 4113) was inactivated in the treatments at 60 °C, however color and pH changed significantly.	Bermúdez-Aguirre and Barbosa-Cánovas (2012)
Cranberry	Nectar	600 W; 60 to 120 μm; 20 kHz; 3 to 9 min	40 and 60 °C	The largest decrease in consistency coefficient was determined after ultrasonic treatment at amplitude 90 μm, 9 min treatment time and the sample temperature of 40 °C.	Šimunek and others (2014)
Grape	Juice	200 W; 0 to 135 Hz; 20 to 40 min	25 to 50 °C	The optimum operating conditions for the maximum inactivation *S. cerevisiae* (ATCC 9763) and the optimal juice quality characteristics were found to be: frequency of 135.0 kHz, temperature of 30.9 °C and time of 40.0 min.	Nafar and others (2013)
Grape	Wine	300 W; 100 kHz; 20 min	20 to 60 °C	Titratable acidity slightly decreased with the increasing of temperature. The electrical conductivity of wine samples decreased when increasing treatment temperature. Total phenolic compounds decreased with the increasing of temperature.	Zhang and others (2016)
Guava	Juice	1500 W; 21% to 40%; 20 kHz; 2 to 10 min	20 to 50 °C	Retention of quality parameters was observed at the maximum treatment conditions of 40% amplitude level for 10 min. However when sonication was carried out at a higher temperature (50 °C), degradation of ascorbic acid increased.	Saad and others (2013)

(*Continued*)

Table 10–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Process temperature(s)	Key finding(s)	Reference
Jamun	Juice	80% and 100%; 5 and 10 min	80 and 90 °C	Irrespective of amplitude level or treatment time and temperature, the treatment did not cause significant differences in titratable acidity, pH, reducing sugar.	Shaheer and others (2014)
Litchi	Juice	100 W; 30 kHz; 30 min	~50 °C	Increase in total phenolic content and total flavonoid content	Saikia and others (2015)
Mango	Juice	200 W; 25 kHz; 0 to 10 or 0 to 7 min	50 and 60 °C	Total inactivation of *E. coli* O157:H7 and *Salmonella* Enteritidis was attained with 5-min TMS at 60 °C.	Kiang and others (2013)
Mandarin	Juice	700 W; 25 kHz; 60 min	55 °C	Sonication can be combined with a mild thermal processing in order to achieve the hygienic quality required for food products without affecting their ascorbic acid contents, and hence their nutritional value.	Aguilar and others (2017)
Melon	Juice	500 W; 20% to 100%; 19 kHz	<53 °C	Significant reduction of POD and PPO activities and total inactivation of ascorbate peroxidase. Significant increase of sucrose (53.60%) and glucose (4.24%) concentrations. US processing also caused the reduction of phenolic compounds (30%).	Fonteles and others (2012)
Orange	Juice	400 W; 100 μm; 24 kHz; 2.8 and 5 min	40 and 53 °C	Application of the highest temperature did not significantly increase the inactivation of *E. coli* K12 (DSM 1607) when compared to the lower temperature (~1 to 1.50 log).	Muñoz and others (2011)
Pear	Juice	750 W; 70%; 20 kHz; 10 min	25 to 65 °C	Treatment at 65 °C for 10 min showed the best results in retention of ascorbic acid and other phenolic compounds with significant reduction in PPO, POD and PME enzymatic activities and complete inactivation of microbes.	Saeeduddin and others (2015)
Pineapple	Juice	400 W; 120 μm; 24 kHz; 0 to 10 min	40 to 60 °C	*S. cerevisiae* (ATCC 4113) was inactivated in the treatments at 60 °C, however, color, and pH changed significantly.	Bermúdez-Aguirre and Barbosa-Cánovas (2012)
Prickly pear	Juice	1500 W; 60% to 90%; 20 kHz; 1 to 5 min	30 to 68.5 °C	*E. coli* reduced by 5 log CFU/mL.	Cruz-Cansino and others (2016)
Sour orange	Juice	5 to 25 W; 60 to 100 min	40 to 80 °C	Up to 8.92% residual PME activity. At higher temperature range (60 °C < T < about 70 °C), combination of sonication and heat showed a synergistic effect on enzyme inactivation process as compared with both the lower temperature range and the thermal inactivation alone.	Koshani and others (2014)
Soursop	Juice	500 W; 20% to 100%; 19 kHz; 2 to 10 min	<60 °C	Good retention of phenolic compounds. Good sensorial acceptance.	Dias and others (2015)
Strawberry	Juice	600 W; 60 to 120 μm; 20 kHz; 3 to 9 min	40 and 55 °C	Low anthocyanin degradation. Only in the case of TMS at 55 °C/9 min the total content of anthocyanins, compared to untreated juice, was reduced by 5.8% to 7.1%.	Dubrović and others (2011)
Sugarcane	Juice	750 W; 0% to 100%; 20 kHz; 2 to 10 min	10 and 50 °C	The time required for 5 log bacterial reduction by TMS was also reduced by 60% as compared to sonication.	Garud and others (2017)
Sweet lime	Juice	400 W; 50 kHz; 5 to 20 min	60 to 80 °C	Inactivation of PME at 80 °C for 20 min.	Siwach (2012)
Watermelon	Juice	100 W; 30 KHz; 30 min	50 °C	Increase of total phenolic content.	Saikia and others (2015)
			Manothermosonication		
Apple	Juice	450 W; 110 μm; 20 kHz; 200 kPa; 0 to 4 min	50 to 60 °C	Synergism was observed towards *L. monocytogenes* (ATCC 15313, ATCC 19111, and STCC 5672) by MTS at 60 °C.	Guzel and others (2014)
Apple	Cider	750 W; 20 kHz; 400 kPa; 0 to 4 min	59 °C	A 5 log reduction of *E. coli* K12 was achieved in 1.4 min.	Lee and others (2013a)
Apple, carrot	Juice blend	100 to 300 kPa; 15–75 s	40 to 60 °C	5 log reduction of *E. coli* 0157:H7 for juice processing was achieved in 30 s for a MTS treatment at 60 °C.	Kahraman and others (2017)
Apple, mango, orange, pineapple	Smoothie	1000 W; 31 μm; 20 kHz; 200 kPa; 12 to 32 μs	<52 °C	Microbial reduction of *L. innocua* (NCTC 11288) of about 3 log.	Palgan and others (2012)
Carrot, orange	Juice blend	1000 W; 20 kHz; 400 kPa; 2.2 min	<63 °C	MTS achieved a 78% inactivation of the PME enzyme.	Caminiti and others (2012)

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Table 10–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Process temperature(s)	Key finding(s)	Reference
Orange	Juice	450 W; 110 μm; 20 kHz; 200 kPa; 0 to 4 min	50 to 60 °C	Treatments are effective towards *L. monocytogenes* (ATCC 15313, ATCC 19111, and STCC 5672) and *E. coli* (ATCC 11303, ATCC 27325) *E. coli* O157:H7 (VTEC-Phage type 34) loads.	Guzel and others (2014)
			Ultraviolet radiation		
Apple	Juice	27.1 J/mL; 254 nm; 3.58 min	55.0°C	5 log reduction of *E. coli* cocktail (STCC 4201, STCC 471, ATCC 27325, ATCC 25922) and *E. coli* O157:H7 without affecting pH, soluble solids, and acidity.	Gayán and others (2013)
Orange	Juice	23.72 J/mL; 254 nm; 3.6 min	55 °C	5 log reduction *E. coli* cocktail (STCC 4201, STCC 471, ATCC 27325, ATCC 25922) and *E. coli* O157:H7. The selected treatment did not affect the pH, acidity, soluble solids, and color, and decreased ascorbic acid and PME 16.45% and 63.96%.	Gayán and others (2012)
			Dense-phase carbon dioxide		
Apple	Juice	20 MPa; 30 min	37 to 62 °C	The aerobic bacteria treated by DPCD at ≥52 °C were almost totally inactivated. The yeasts and molds treated by DPCD at ≥42 °C were totally inactivated.	Liao and others (2010b)
Banana	Juice	20 MPa; 30 min	45 to 60 °C	Residual PPO in the juice was 40.7% at 45 °C at 11.6% when the temperature increased to 60 °C.	Yu and others (2013)
Beetroot	Juice	10 to 60 MPa; 10 to 30 min	31 to 55 °C	The inactivation of PPO, POD, PE, and PG followed a first order reaction. The highest degradation of bethacyanins, bethaxanthins and polyphenols occurred at 60 MPa at 55 °C, for 30 min: 58%, 32%, and 30%, respectively.	Marszałek and others (2017a)
Carrot	Juice	10 to 60 MPa; 10 to 30 min	31 to 55 °C	Most efficient parameters for PPO, PE and PG enzymes inactivation were noted at 10 MPa and 47 °C.	Marszałek and others (2016)
Celery	Juice	10 to 60 MPa; 10 to 30 min	31 to 55 °C	The optimal inactivation was found at 30 MPa, 47 °C (for POD and PE) and 60 MPa, 55 °C (for PPO).	Marszałek and others (2016)
Chokeberry	Drink fortified with herbal extracts	65 MPa; 30 min	55 °C	Retention of anthocyanins of drink in comparison with thermal pasteurization. Slight decrease (9%) of total content of polyphenols.	Skąpska and others (2016)
Melon	Juice	8 to 35 MPa; 5 to 60 min	35 to 65 °C	At 35 MPa, 55 °C, 60 min, the microorganisms were totally inactivated. The least residual activity of PPO, POD and LOX was 25.26%, 38.46%, and 0.02% at 35MP, respectively.	Chen and others (2010)
Mulberry	Juice	15 MPa; 10 min	55 °C	Increase of antioxidant capacity, viscosity, total phenols and total anthocyanins. More than 2 log CFU/mL of total aerobic bacteria, and yeasts and molds were detected in DPCD-treated juice for 21 d at 4 °C and 14 d at 25 °C, respectively.	Zou and others (2016)
Strawberry	Juice	10 to 60 MPa; 10 to 30 min	35 to 65 °C	The highest level of POD inactivation (95%) was achieved at a temperature of 65 °C irrespective of the pressure and time applied. Anthocyanins were well preserved; only at a temperature of 65 °C, a significant decrease of 10% was reported.	Marszałek and others (2015b)
Watermelon	Juice	30 MPa; 2.5 to 30 min	30 to 50 °C	The maximum reduction of PPO activity was 95.8% at 30 MPa and 50 °C for 30 min.	Liu and others (2013)
			Ozonation		
Apple	Juice	2 to 3 g/m^3 O_3; 20 to 60 s	25 to 55 °C	Combination of ozone and heat for 1 min reduced *E. coli* O157:H7 by 1.50 and 1.60 log CFU/mL, respectively, at 25 and 45 °C, and below the detection limit at 50 and 55 °C.	Sung and others (2014)

Table 11–Improving the effectiveness of nonthermal treatments—Approach 3: A pplication of heat before or after nonthermal process.

Fruit/vegetable source(s)	Product	Nonthermal treatment conditions	Heating conditions	Key finding(s)	Reference
			High hydrostatic pressure		
Black mulberry	Juice	250 to 480 MPa; 10 to 25 min	75 to 85 °C; 2 to 5 min	Optimal treatment conditions were 83.39 °C, 2.38 min, 480.00 MPa, and 21.67 min (temperature, heating time, pressure, and pressurising time). At these levels, the corresponding response variables were 91.68%, 44.69%, and 20.17% for the amounts of anthocyanin retained, and residual activities of PPO and POD, respectively.	Engmann and others (2014b)
			High pressure homogenization		
Carrot	Juice	100 MPa; 20 °C	~98 °C; 3 min	Low sediment for 2 wk under refrigeration temperature.	Yu and Rupasinghe (2013)
			Ultra-high-pressure homogenization		
Mango	Nectar	200 and 300 MPa	61.5 °C; 20 min and 73.5 °C; 10 min	Combined treatment reduced *A. niger* (IOC 4573) by 5 log CFU/mL, with a synergistic effect. Positive effect on color, in particular for samples treated at 200 MPa + 61.5 °C/20 min.	Tribst and others (2011)
			Thermosonication		
Apple	Juice	200 W; 24 kHz; 100%; 0 to 70 min; 65 to 75 °C	80 °C; 30 min	*N. fischeri* (JCM 1740) spores are more sensitive to the US + heat than heat alone.	Evelyn and others (2016)
Orange	Juice	200 W; 100%; 24 kHz; 1 min; <78 °C)	80 °C; 10 min	The pretreatment of juice with a heat shock (80 °C, 10 min) followed by US caused a 2-fold increase of the inactivation of *Al. acidoterrestris* (NZRM 4447).	Evelyn and Silva (2016)
			Ultraviolet radiation		
Pineapple	Juice	5.61 to 11.23 mJ/cm^2	50 to 60 °C; 10 to 30 min	Treating pineapple juice with mild heat at 55 °C for 10 min and UV at 5.61 mJ/cm^2 decreased PME by 60.53% while retaining ~ 61.57% and 72.80% of bromelain and total phenolic content, respectively.	Sew and others (2014)
			Gamma radiation		
Ginger	Ready-to-drink beverage	1 to 3 kGy	95 °C; 2 min	With 2 to 3 kGy dose, ginger beverage remained microbiologically safe. However, considering the other quality parameters and the stability of principal active component during subsequent storage (up to 6 mo at 18 to 33, 5, and 37 °C), irradiation may not be beneficial for the preservation of the beverage.	Dadasaheb and others (2015)
Indian borage	Ready-to-drink beverage	1 to 3 kGy	95 °C; 2 min	With 2 to 3 kGy dose, Indian borage beverage remained microbiologically safe. However, considering the other quality parameters and the stability of principal active component during subsequent storage (up to 6 mo at 18 to 33, 5, and 37°C), irradiation may not be beneficial for the preservation of the beverage.	Dadasaheb and others (2015)
Papaya	Nectar	5.0 and 7.5 kGy	80 °C; 5 min	Radiation followed by heat further enhanced the destruction of *L. innocua* and *Cl. sporogenes* and retained the flavour and a nutritional profile closest to untreated controls. The product was microbiologically safe with acceptable enzyme levels and would be shippable under refrigeration.	Parker and others (2010)
			Ultrafiltration		
Apple	Juice	Ceramic membrane 0.05 μm; 0.3 MPa; 25 °C	110 °C; 8.6 s	Total plate count and yeasts and molds were <1 log CFU/mL.	Zhao and others (2014)
Blueberry	Juice	Polyvinylidene fluoride membrane 0.2 μm, 0.864 m^2; ~25 °C	90 °C; 10 s	Pasteurization resulted in greater volatile losses in nonclarified juice (11.5%) compared to UF-clarified juice (0.8%)	Beaulieu and others (2016)
Cucumber	Juice	Ceramic membrane 0.05 μm, 0.1 m^2; 0.3 MPa; 25 °C	110 °C; 8.6 s	Total aerobic bacteria and yeasts and molds in the juice were reduced <1 log CFU/mL, and showed no outgrowth after refrigerated storage of 20 d.	Liu and others (2016)
Pear	Juice	Ceramic membrane 0.05 μm, 0.1 m^2; 0.3 MPa; 25 °C	110 °C; 8.6 s	Total plate count and yeasts and molds were reduced below the detection level.	Zhao and others (2016)

Table 12–Improving the effectiveness of nonthermal treatments—Approach 4: Combined technologies.

Fruit/vegetable source(s)	Product	Combined technologies		Key finding(s)	Reference
Combination of pulsed electric fields with other nonthermal treatments					
Apple	Juice	PEF 12 to 15 Hz; 24 to 34 kV/cm; 1 μs; 89 μs	PL 4.0 and 5.1 J/cm^2; 1.20 and 1.52 μs	A minimum microbial reduction of *E. coli* K12 (DSM 1607) of 5 log. Any effect on quality and sensorial attributes.	Caminiti and others (2011b)
Apple	Concentrated juice	PEF 500 and 2500 V/cm; 2000 μs	US 330 W; 10 min	Inactivation of *Al. acidoterrestris* spores.	Djas and others (2011)
Apple, cranberry	Juice blend	PEF 18 Hz; 34 kV/cm; 1 μs; 93 μs	UV 5.3 J/cm^2; 200 to 280 nm; 30 s	No effect on color, odor and flavor. High sensory acceptance.	Caminiti and others (2011a)
Apple, cranberry	Juice blend	PEF 18 Hz; 34 kV/cm; 1 μs; 93 μs	PL 3.3 J/cm^2; 360 μs; <30 °C	No effect on color, odor and flavor. High sensory acceptance	Caminiti and others (2011a)
Apple, mango, orange, pineapple	Smoothie	PEF 1 kHz; 34 kV/cm; 32 μs	MTS 1000 W; 100%; 20 kHz; 200 KPa; <52 °C	*L. innocua* (NCTC 11288) reduced by 4.2 to 5.6 log CFU/mL.	Palgan and others (2012)
Carrot, orange	Juice blend	PEF 18 Hz; 24 kV/cm; 1 μs; 89 μs; <49 °C	MTS 1000 W; 20 kHz; 400 kPa; 2.2 min; <63 °C	19% PME residual activity. Good preservation of flavor. Any significant changes on the phenolic content and pH.	Caminiti and others (2012)
Grapefruit	Juice	PEF 1 kHz; 20 kV/cm; 600 μs; <45 °C	US 420 W; 28 kHz; 30 min; 20 °C	No significant changes in pH, acidity, soluble solids and electrical conductivity. A significant decrease in viscosity and increase in cloud value.	Aadil and others (2015a)
Tomato	Juice	PEF 100 Hz; 35 kV/cm; 1500 μs; 4 μs	US 400 W; 20 kHz; 20%; 7 min; <65 to 70 °C	The treatment was effective in terms of total lycopene bioaccessibility (15.6%) in comparison to the thermally treated samples (4.95%).	Jayathunge and others (2017)
Combination of ultraviolet radiation with other nonthermal treatments					
Apple	Juice	UV 254 nm; 12 s; 25 to 40 °C	RFEF 20 kHz; 15 kV; 1.6 μs; 170 μs; 25 to 40 °C	Treatment combination at 25, 30 and 40 °C, caused a decline in the surviving populations of *E. coli* K-12 cells to 4, 3.3, and 1.5 log CFU/mL, respectively.	Ukuku and Geveke (2010)
Apple	Juice	UV 254 nm	TS 400 W; 50% and 100%; 24 kHz; 5 and 10 min; 40 to 60 °C	89.3% PPO enzyme inactivation. Increase in color parameters.	Başlar and Ertugay (2013)
Apple	Juice	UV 254 nm; 40 W	US 20 kHz; 120 μm; ~35 °C	Combined treatment was more effective in *Z. bailii* inactivation than individual US or UV treatments.	Gómez-Díaz and others (2011)
Apple, cranberry	Juice blend	UV 5.3 J/cm^2; 200 to 280 nm; 30 s	MTS 750 W; 23 μm; 20 kHz; 8.4 min; <58 °C	No significant changes in nonenzymatic browning, total phenolics and antioxidant activity of the juices. Low sensory acceptance.	Caminiti and others (2011a)
Carrot	Juice	UV 254 nm	US 100 W; 50%; 20 kHz; 15 min; <30 °C	High retention of phenolic content and antioxidant activity as well as the free radical scavenging activity.	Khandpur and Gogate (2015)
Carrot, orange	Juice blend	UV 10.62 J/cm^2; 1 min	MTS 1000 W; 20 kHz; 400 kPa; 2.2 min; <63 °C	24% PME residual activity. High preservation of flavor. Any significant changes in the phenolic content and pH.	Caminiti and others (2012)
Mango	Juice	UV 3.525 J/m^2; 254 nm; 15 and 30 min; ~25 °C	US 68 to 72 W; 40 kHz; 15 and 30 min; 25 °C	A significant increase in extractability of carotenoids (15%), polyphenols (37%), flavonoids (35%), and enhancement of the antioxidant capacity.	Santhirasegaram and others (2015c)
Orange	Juice	UV 254 nm	US 100 W; 50%; 20 kHz; 15 min; <30 °C	High retention of phenolic content and antioxidant activity as well as the free radical scavenging activity.	Khandpur and Gogate (2015)

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Table 12–Continued.

Fruit/vegetable source(s)	Product	Combined technologies		Key finding(s)	Reference
Spinach	Juice	UV 254 nm	US 100 W; 50%; 20 kHz; 15 min; <30 °C	High retention of phenolic content and antioxidant activity as well as the free radical scavenging activity.	Khandpur and Gogate (2015)
Sweet lime	Juice	UV 254 nm	US 100 W; 50%; 20 kHz; 15 min; <30 °C	High retention of phenolic content and antioxidant activity as well as the free radical scavenging activity.	Khandpur and Gogate (2015)
Combination of pulsed light with other nonthermal treatments					
Apple	Juice	PL 4.03 and 5.1 J/cm^2; 360 μs; 35 °C	TS 400 W; 100 μm; 24 kHz; 2.9 and 5 min; 40 and 53 °C	When the technologies were applied individually the maximum reduction of *E. coli* K12 achieved was 2.7 to 4.9 log CFU/mL, while most of the combined treatments achieved a 6 log-reduction.	Muñoz and others (2012)
Apple	Juice	PL 2.4 to 71.6 J/cm^2; 2 to 60 s; <12 °C	US 600 W; 95.2 μm; 20 kHz; 10 and 30 min; 20 to 44 °C	Combination of these technologies led up to 3.0 log CFU/mL of *Al. acidoterrestris* (ATCC 49025) spores reduction in commercial apple juice and 2.0 log CFU/mL in natural juice; whereas for *S. cerevisiae* (KE162), 6.4 and 5.8 log CFU/mL of reduction were achieved in commercial and natural apple juices, respectively.	Ferrario and others (2015)
Apple, cranberry	Juice blend	PL 3.3 J/cm^2; 360 μs; <30 °C	MTS 750 W; 23 μm; 20 kHz; 8.4 min; <58 °C	No significant changes were found in nonenzymatic browning, total phenolics and antioxidant activity of the juices. Low sensory acceptance.	Caminiti and others (2011a)
Carrot, orange	Juice blend	PL 3.3 J/cm2; 360 μs; <30 °C	MTS 1000 W; 20 kHz; 400 kPa; 2.2 min; <63 °C	23% PME residual activity. Good preservation of flavor. Any significant changes in the phenolic content and pH.	Caminiti and others (2012)
Orange	Juice	PL 4.03 and 5.1 J/cm^2; 2.22 and 2.81 s	TS 400 W; 100 μm; 24 kHz; 2.9 and 5 min; 40 and 53 °C	From 2.5 to 3.93 log inactivation of *E. coli* K12 (DSM 1607)	Muñoz and others (2011)
Combination of high hydrostatic pressure with other nonthermal treatments					
Apple	Juice	HHP 250 to 450 MPa; 10 min; room temperature	US 500 W; 70%; 25 kHz; 60 min; 20 °C	The combined US-HHP450 treatment caused highest inactivation of PME, PPO and POD. The complete inactivation of total plate counts, yeasts and molds. A significant improvement of phenolic compounds, ascorbic acid, antioxidant capacity, radical scavenging activity and color values.	Abid and others (2014)
Apple	Juice	HHP 250 to 600 MPa; 1 min; 25 °C	TUVP 16 W; 0.82 and 8.45 J cm^2; 254 nm	*L. monocytogenes* (ATCC 15313), and *S. aureus* (ATCC 25923) were completely inactivated when treated with a combination of TUVP (8.45 J/cm^2) and HHP (500 MPa).	Shahbaz and others (2016)
Ashitaba	Juice	**HHP** 550 MPa; 90 s; room temperature	**TUVP** 35 W; 25 mW/cm^2; 254 nm	No colonies of yeasts and molds, coliform bacteria, *Pseudomonas*, or *B. cereus* were detected after processing.	Chai and others (2014)
Cranberry	Prebiotic juice fortified with FOS	**HHP** 450 MPa; 5 min; 11.5 °C	**US** 500 W; 18 kHz; 5 min; room temperature	The treatment preserved FOS content maintaining the prebiotic property of the juice. High retention of organic acids (>90%) and an increase in anthocyanin content (up to 24%). The changes in instrumental color, soluble solids content and pH were negligible.	Gomes and others (2017)
Orange	Juice	**HHP** 400 MPa; 1 min; 25 °C	**TUVP** 35 W; 17 mW/cm^2; 254 nm; 0 to 20 min	4.7 log reduction of *E. coli* O157:H7 (NCTC 12079) reduction after decontamination of orange surfaces by TUVP treatment.	Yoo and others (2015)
Orange	Juice	**HHP** 200 and 600 MPa; 15 min; <39 °C)	**TS** 200 W; 100%; 24 kHz; 0 to 60 min; 78 °C	HHP pretreatments enhanced the spore inactivation of *Al. acidoterrestris* (NZRM 4447) in juice by further TS.	Evelyn and Silva (2016)
Combination of dense phase carbon dioxide with other nonthermal treatments					
Apple	Juice	DPCD 100 to 350 bar; 36 °C or 225 bar; 31 to 41 °C	US ~40 W; 30 kHz; 5 min	Combined treatment inactivated of *E. coli* (DH1) and *S. cerevisiae* (T73).	Ortuño and others (2014b)

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Table 12–Continued.

Fruit/vegetable source(s)	Product	Combined technologies		Key finding(s)	Reference
Coconut	Water	DPCD 12 MPa; 15 min; 40 °C	US 10 W	5 log reduction achieved for natural microbial flora in about 15 min while about 30 min were needed for DPCD treatment alone. A full shelf life of 4 wk was assured.	Cappelletti and others (2014)
Orange	Juice	DPCD 100 to 350 bar; 36 °C or 225 bar; 31 to 41 °C	US ~40 W; 30 kHz; 5 min	The inactivation rate of *E. coli* (DH1), *S. cerevisiae* (T73) and PME increased with pressure and temperature. For example, a reduction of 4.12, 4.62, and 6.15 log cycles of *E. coli* was obtained after 1 min of treatment, at 31, 36, and 41 °C, respectively.	Ortuño and others (2014a)
Combination of membrane processing with other nonthermal treatments					
Apple	Juice	UF Ceramic membrane 0.05 μm; 0.3 MPa; 25 °C	HHP 500 MPa; 6 min; <40 °C	Low browning degree and high total phenols and clarity, as well as volatile aroma compounds retention. Fresh apple juice processed by UF + HHP was microbiologically safe during 60 d of storage at 4 °C.	Zhao and others (2014)
Apple	Juice	UF Fat sheet polyethersulfone membrane 30 kDa; 276 to 690 kPa	DCEF 0 to 800 V/m	Application of DCEF resulted in a significant augmentation of permeate flux.	Sarkar (2015)
Apple	Cider	MF Ceramic membrane 0.8 and 1.4 μm; 155 kPa; 10°C	UV 254 nm; 1.75 mJ/cm^2	The combined MF and UV achieved more than a 5 log reduction of *E. coli*, *Cryptosporidium parvum*, and *Al. acidoterrestris*.	Zhao and others (2015a)
Beet roots	Juice	UF Hydrophilic polyethersulfone membrane 10 to 100 kDa; 0.5 to 3.7 bar; ~22 °C	PEF 200 Hz; 600 V/cm; 0.05 s; 30 and 70 °C	Filtration of PEF-obtained juice resulted in high purity and low coloration. However filtrate purity increased and coloration decreased with decrease of nominal molecular weight cut-offs from 100 to 10 kDa.	Loginov and others (2011)
Cucumber	Juice	UF Ceramic membrane 0.05 μm, 0.1 m^2; 0.3 MPa; 25 °C	HHP 500 MPa; 5 min, <35 °C	Total aerobic bacteria and yeasts and molds in the juice were reduced to be <1 log cycle, and showed no outgrowth after refrigerated storage of 20 d. HHP-treated juice showed less total color change, higher clarity, and retained more key aroma compounds than heat-treated juice. Moreover, HhP-treated juice always showed higher scores for overall acceptability than heat-treated juice.	Liu and others (2016)
Pear	Juice	UF Ceramic membrane 0.05 μm, 0.1 m^2; 0.3 MPa; 25 °C	HHP 400 and 500 MPa; 2 to 10 min; ~25 °C	Total plate count and yeast and molds were reduced below the detection level. During 56 d of refrigerated storage, all samples showed microbial safety, as well as low decrease in total phenols and antioxidant capacity.	Zhao and others (2016)
Pomegranate	Juice	MF Hydrophilic mixed cellulose ester membrane 0.45 μm, 78 $\times$ 10^{-4} m^2	US 80 to 150 W; 28–32 kHz; <50 °C	The cake layer thickness in the presence of ultrasound waves is much lower than its thickness in the absence of US waves. On the other hand, the presence of US waves in the membrane clarification increases the standard blocking.	Aghdam and others (2015)
Sweetlime	Juice	Forward osmosis A thin and dense semi-permeable skin layer made of cellulose triacetate embedded in a nylon mesh 50 to 100 μm; ~27 °C)	US 30 kHz	US-assisted forward osmosis process showed high rates of flux. The combined process resulted in attaining high concentration of the sweet lime juice (4.14-fold).	Chanukya and Rastogi (2017)
Combinations of membrane processing technologies					
Açai	Juice	MF α-alumina tubular membrane 0.2 μm, 0.022 m^2; 2 bar; ~35 °C	NF Semi-aromatic piperazine-based polyamide layer on top of a polysulphone microporous support, or aromatic polyamide, or thin film, or polietersulfone membranes, 10 to 30 bar; 35 °C	Anthocyanins retention above 99%.	Couto and others (2011b)

(*Continued*)

Table 12–Continued.

Fruit/vegetable source(s)	Product	Combined technologies		Key finding(s)	Reference
Apple	Juice	UF Polyethersulphone membrane 200 cm^2; 10 and 100 kDa	OD polypropylene membrane 0.1 m^2, 0.2 μm; ~25°C and/or MD Polypropylene membrane 0.1 m^2, 0.2 μm; ~20 °C	The product characteristics were very similar to that of the initial apple juice especially regarding the retention of bright natural color and pleasant aroma, which are significantly lost during conventional thermal evaporation.	Onsekizoglu and others (2010)
Apple	Juice	UF Tubular polysulphone Membrane 8 kDa; 50°C	RO Tubular composite polyamide film membrane 0.9 m^2; 2 to 4 MPa; 25 to 27 °C	The combined treatment led to a volume concentration factor of 1.56.	Echavarría and others (2012)
Apple	Concentrated juice	MF Polymeric membrane 0.05 m^2, 0.3 μm; 2 bar; 30 °C	RO Thin film composite membranes 0.36 m^2; 6 MPa + OD Fat sheet polytetrafluoroethylene membrane 0.032 m^2; 20 kPa; 30 °C	Slight differences in pH and acidity. The juices concentrated by RO and OD presented acceptance percentages (scores between 6 and 9) of 58% and 55%, respectively.	Aguiar and others (2012)
Banana	Juice	MF 76 kPa; 0.0124 m^2	UF Surface-modified polysulfone-based membrane; 10 to 44 kDa; 25 °C	The juice could be successfully stored for 1 mo without any additive and preservative, keeping its natural nutritional qualities, taste, and flavor intact.	Sagu and others (2014b)
Bergamot	Juice	UF Polysulphone hollow fibre membrane 100 KDa; 0.7 bar; 24 °C	UF Fluoropolymer membrane 1000 Da; 9 bar; 24 °C or NF TiO_2 membrane 450 and 750 Da; 7.5 and 33 bar; 24 °C	The best separation of polyphenols and sugars occurred by using a 450 Da NF membrane.	Conidi and others (2011)
Bergamot	Juice	UF Hollow fibers membrane 100 kDa, 0.16 m^2; 0.7 bar; 24 °C	OD Macroporus polypropylene hollow fibers membrane 0.2 μm, 1.4 m^2; 0.48 bar; 25 °C	Flavonoids and ascorbic acid were recovered in the UF permeate and well preserved during the subsequent concentration process.	Cassano and others (2013)
Blackberry	Juice	MF Tubular ceramic membrane 0.2 μm; 0.1 to 0.3 MPa; ~35 °C) + OD Hydrophobic polypropylene hollow fibers membrane 0.2 μm	NF Seven flat-sheet nanofiltration membranes 150 to 300 Da, ~1 nm; 0.5 to 3 MPa; 30 °C	The highest permeate flux retained over 90% of total soluble solids and 100% of anthocyanins and ellagitannins.	Acosta and others (2017)
Blackcurrant	Juice	VMD Polypropylene membrane 0.2 μm + RO Polyamide film membrane 60 Da	NF Polyamide film ~1.12 nm + DCMD Polypropylene membrane 0.2 μm	The economical potential of combined technologies is very promising, since the price of the processing is lower or at least within the range of conventional industrial processing.	Sotoft and others (2012)
Bottle gourd	Juice	MF 0.2 μm; 123 kPa	UF Cellulose acetate phthalate/polyacrylonitrile blend hollowfiber membranes 35 to 104 kPa; 30 min	All the nutritional parameters (total protein, polyphenol, sodium, potassium and total soluble solids) including taste were monitored and it was found that the quality of the juice was maintained with a positive purchase intention.	Mondal and others (2016)

(*Continued*)

Table 12–Continued.

Fruit/vegetable source(s)	Product	Combined technologies		Key finding(s)	Reference
Camu–camu	Juice	RO Thin film composite membrane 0.288 m^2; 60 bar; 20 °C	OD Thin polytetrafluoroethylene selective layer supported by a polypropylene macro porous layer 0.032 m^2, 0.2 μm, 0.2 bar; 20 to 35 °C	The use of integrated membrane processes reached concentration levels up to 7 times for camu–camu juice's bioactive compounds.	Souza and others (2013)
Coconut	Water	MF 2.5 μm; ~25 °C	MF 0.45 μm; ~25 °C	Gradual degradation of chemical composition during the storage at 4 °C.	Das Purkayastha and others (2012)
Grape	Juice	UF Tubular ceramic membranes 0.05 μm; 1 bar; 40°C	RO Composed film membranes of spiral type 63.5 mm; 40 bar; 30 and 40°C	The permeate flux exhibited values of 8.51 and 4.65 kg/m^2 h at 30 and 40 °C, respectively.	Campos and others (2016)
Grape	Wine	RO Cellulose triacetate/diacetate blend on polyester membranes; 0 to 30°C + NF Polyamide type thin film composite on polyester membrane; 0 to 50 °C	PM Polyoctylmethylsiloxane supported in polyetherimide membrane 107.5 cm^2; 1.0 mbar; 12 °C	High effectiveness of NF in alcohol removal from wine. The addition of pervaporated aroma compounds to the dealcoholized wine samples increased the flavour sensations during the wine tasting.	Catarino and Mendes (2011)
Grape	Juice	MF Ceramic membrane 0.2 μm, 0.162 m^2	NF Multitubular ceramic membrane 1 and 8 kDa, 0.0132 m^2; 7.5 bar; 30 and 40 °C	The sugar concentration of permeate increased at 1 kDa and 30°C was 194.5 g/L. For the 8 kDa UF ceramic membrane, increasing the temperature from 30 to 40 °C produced an increase in the permeate flux.	Cancino-Madariaga and others (2012)
Mandarin	Juice	UF Tubular polysulphone Membrane 8 kDa; 50 °C	RO Tubular composite polyamide film membrane 0.9 m^2, 2 to 4 MPa; 25 to 27 °C	The combined treatment led to a volume concentration factor of 1.49.	Echavarría and others (2012)
Orange	Juice	UF Polysulfone hollow fiber membrane 100 kDa, 1.2 m^2; 75 kPa; ~23 °C)	OD Polypropylene hollow fiber membranes 0.2 μm, 0.1 m^2; ~24 °C	The clarified juice was concentrated from 9.5 to 65 °Brix. In the final product the organoleptic, nutritional and antioxidant properties of the fresh juice are efficiently preserved.	Quist-Jensen and others (2016)
Peach	Juice	UF Tubular polysulphone Membranes 8 kDa; 50 °C	RO Tubular composite polyamide film membrane 0.9 m^2; 2 to 4 MPa; 25 to 27 °C	The combined treatment led to a volume concentration factor of 1.58.	Echavarría and others (2012)
Pear	Juice	UF Tubular polysulphone membranes 8 kDa; 50 °C	RO Tubular composite polyamide film membrane 0.9 m^2, 2 to 4 MPa; 25 to 27 °C	The combined treatment led to a volume concentration factor of 1.53.	Echavarría and others (2012)
Pomegranate	Juice	UF Modified poly(ether ether ketone) hollow fibers membrane 46 cm^2; 0.96 bar; ~25 °C	OD Microporous polypropylene hollow fibers membrane 0.2 μm, 1.4 m^2; 25 °C	Rejections of the UF membrane towards polyphenols and anthocyanins were of 16.5% and 11.7%, respectively. The antioxidant activity of pomegranate aril juice was efficiently preserved during the subsequent concentration step.	Cassano and others (2011)

(*Continued*)

Table 12–Continued.

Fruit/vegetable source(s)	Product	Combined technologies		Key finding(s)	Reference
Pomegranate	Juice	UF PVDF membrane 0.0055 m^2, 30 kDa; 3 bar; ~25 °C	OD Polypropylene membrane 0.1 m^2, 0.2 μm; 1.6 bar; 5 to 40 °C and/or MD Polypropylene membrane 0.1 m^2, 0.2 μm, 1.6 bar; 5 to 40 °C	The combined treatment was effective in preventing the original characteristics of the clarified juice.	Onsekizoglu (2013)
Pomegranate	Juice	UF Cellulose triacetate membrane 0.26 m^2, 150 kDa; 0.6 bar; ~25 °C	MF Composite fluoro polymer, or polyethersulphone and Thin-film composite membranes 1000 to 4000 Da; 10 or 5 to 25 bar, ~25 °C	The yields of polyphenols and anthocyanins in the retentate stream were 84.8% and 90.7%, respectively. The diafiltration step allowed to obtain a recovery efficiency in the permeate side for glucose and fructose up to 90% and 93%, respectively.	Conidi and others (2017)
Sour cherry	Juice	MF Tubular ceramic membrane 0.45 μm; 1.5 bar; 25 °C + RO Spiral wound membrane; 30 bar; 30 °C	OD Hollow fibre polypropylene porous membrane 0.2 μm, 0.2 m^2; 30 °C	The combined treatment led to a significant loss of total antioxidant activity and total polyphenolic content.	Rácza and others (2014)
Tomato	Juice	MD Polypropylene membrane 0.1 m^2, 0.2 μm	OD Polypropylene membrane 0.1 m^2, 0.2 μm	Membrane system was more advantageous innterms of the formation of HMF and furan comparing to the conventional method.	Savaş Bahçeci and others (2015)
Combination of nonthermal treatments with alternative thermal technologies					
Apple	Juice	UV 254 nm; 160 to 290 s	OH 1485 V/m; 45 to 65 °C	The highest lethal rate (~6.30 log reduction) of *E. coli* K12 was obtained for samples treated with the UV/OH combination at 65 °C.	Lee and others (2013b)
Orange	Juice	US 200 to 1000 W; 3 to 15 min	MWH 200 to 800 W; 20 to 60 °C	The optimum processing condition for inactivation of *S. cerevisiae* was: 350 W microwave power, 35 °C temperature, 778.2 W ultrasonic power and 11 minutes of exposure. The appearance of the orange juice in the combinative method was better than those of conventional method (57% vs. 43%).	Samani and others (2015a)
Peach	Juice	TS 150 W; 21 kHz; 30 min; <88 °C	MWH 1500 W; 140 °C; 30 min	The application of MW/TS protocol does not eliminate Pru p 3 IgE binding properties.	Garino and others (2012)
Sour Cherry	Juice	US 200 to 1000 W; 3 to 15 min	MWH 200 to 800 W; 20 to 60 °C	The optimum processing condition was: 352.21 W microwave output power, 49.94 °C temperature, 475.13 W ultrasound power and 6 min of exposure time. Under this condition, the maximum ascorbic acid content was 142.5 mg per 100 mL.	Samani and others (2015b)
Tomato	Juice	HHP 600 MPa	OH 60 Hz; 0 to 50 V/cm; 0 to 30 min; 105 °C	*B. amyloliquefaciens* (TMW 2.479 Fad 82) and *G. stearothermophilus* (ATCC 7953) spores were reduced by 3.1 and 4.8 log, respectively, for a 10 min holding time.	Park and others (2013)

Table 13–Improving the effectiveness of nonthermal treatments—Approach 5: Combination with antimicrobials.

Fruit/vegetable source(s)	Product	Processing conditions	Antimicrobial(s)	Key finding(s)	Reference
			Pulsed electric fields		
Apple	Juice	25 kV/cm; <35 °C	citral or (+)-limonene (0.2 μL/mL)	The combination of PEF and citral or (+)-limonene showed additive effects against *Leuconostoc* spp. 75. The combination of PEF and essential oils did not increase either inactivation or injury levels on *S. bayanus* CECT 11185.	Chueca and others (2016)
Apple	Juice	20 to 30 kV; 5 to 125 μs; 20 to 40 °C	Ethyl lauroyl arginate (50 ppm)	The inactivation of *Escherichia coli* O157:H7 by PEF ranged from 0.4 to 3.6 log CFU/mL. When ethyl lauroyl arginate was added to apple juice, a significant increase on the lethal effect of the PEF treatments was observed (0.9 to 6.7 log reduction).	Saldaña and others (2011)
Apple	Juice	30 kV cm; 0 to 45 min; <35 °C	Carvacrol (1.3 mM)	The simultaneous application of PEF and carvacrol caused a 5 log-inactivation of *E. coli* O157:H7.	Ait-Ouazzou and others (2013)
Apple	Juice	180 Hz; 35 kV/ cm; 4 μs; 1575 μs; 30 to 40 °C	Citric acid (1.5%) and cinnamon bark oil (0.10%)	Resident microbial populations only were controlled during the 91 ds of storage at 5 °C with antimicrobials; however, changes on some sensory attributes such as aroma, taste and sourness of juice were perceived.	Mosqueda-Melgar and others (2012)
Mango	Juice	30 kV/cm; 0 to 45 min; <35 °C	Carvacrol (1.3 mM)	The simultaneous application of PEF and carvacrol caused the inactivation of 5 log CFU/mL of *E. coli* O157:H7.	Ait-Ouazzou and others (2013)
Mango, orange, papaya	Juice blend added with oat milk	10 to 40 kV/cm; 40 to 700 μs; <39 °C	*Stevia rebaudiana* Bertoni (2.5% w/v)	Synergic PEF-Stevia effect, achieving inactivation levels of *L. monocytogenes* (CECT 4032) >5 log CFU/mL.	Rivas and others (2016)
Mango, papaya	Juice blend	20 and 40 kV/cm; 100 to 360 μs; ~25 °C	*Stevia rebaudiana* Bertoni (0% to 2.50% w/v)	Stevia addition reduced PEF effectiveness against yeast, molds and mesophiles, but increased its effectiveness against *L. monocytogenes* (CECT 4032).	Belda-Galbis and others (2016)
Orange	Juice	15 Hz; 40 kV/cm; 1 μs; 100 μs; <56 °C	Benzoic acid (100 ppm) and lactic acid (500 ppm)	A synergy was shown between lactic acid and PEF in the inactivation of *L. innocua* (IMD 11288) and *P. fermentans* (CBS189).	McNamee and others (2010)
Orange	Juice	30 kV/cm; 0 to 45 min; <35 °C	Carvacrol (1.3 mM)	The simultaneous application of PEF and carvacrol caused the inactivation of *E. coli* O157:H7 of 5 log CFU/mL.	Ait-Ouazzou and others (2013)
Orange	Juice	180 Hz; 35 kV/ cm; 4 μs; 1575 μs; 30 to 40 °C	Citric acid (1.5%) and cinnamon bark oil (0.10%)	Resident microbial populations only were controlled during the 91 ds of storage at 5 °C with antimicrobials; however, changes on some sensory attributes such as aroma, taste and sourness of juice were perceived.	Mosqueda-Melgar and others (2012)
Pear	Juice	180 Hz; 35 kV/ cm; 4 μs; 1575 μs; 30 to 40 °C	Citric acid (1.5%) and cinnamon bark oil (0.10%)	Resident microbial populations only were controlled during the 91 ds of storage at 5 °C with antimicrobials; however, changes on some sensory attributes such as aroma, taste and sourness of juice were perceived.	Mosqueda-Melgar and others (2012)
Pomegranate	Juice	35 kV/cm; 1 μs; 72 and 281 μs; <55 °C	Potassium sorbate (900 micrograms/mL) + sodium benzoate (PET bottles coated) (1500 mg/mL)	Juices treated with PEF and stored in antimicrobial bottles had a shelf life >84 d under refrigerated conditions	Jin and others (2014)
Prickly pear	Juice	50 Hz; 27 to 36 kV/cm; 11 to 15 μs; 25 °C	Sodium benzoate (300 ppm) + potassium sorbate (100 ppm)	The combination of preservatives and PEF had a synergistic effect on *S. cerevisiae* (ATCC 26109), achieving at least 3.4 log reduction immediately after processing, and more than 5 log at fourth d of storage at 25 °C.	García- García and others (2015)
Strawberry	Juice	18.6 kV/cm; 2.6 μs; 150 μs; 45 to 55 °C	Sodium benzoate (750 ppm) + potassium sorbate (350 ppm) and sodium benzoate (750 ppm) + potassium sorbate (350 ppm) + citric acid (2.7%)	A reduction of 5.11 log CFU/mL at 55 °C, while in the sample without preservatives, a decrease of 3.79 log was achieved. In addition, sodium benzoate, potassium sorbate and citric acid induce sublethal injury and enhance PEF inactivation of *E. coli* O157:H7 and nonpathogenic *E. coli* (ATCC 35218).	Gurtler and others (2011)

(*Continued*)

Table 13–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Antimicrobial(s)	Key finding(s)	Reference
Strawberry	Juice	180 Hz; 35 kV/ cm; 4 μs; 1575 μs; 30 to 40 °C	Citric acid (1.5%) and cinnamon bark oil (0.10%)	Resident microbial populations only were controlled during the 91 ds of storage at 5 °C with antimicrobials; however, changes on some sensory attributes such as aroma, taste and sourness of juice were perceived.	Mosqueda-Melgar and others (2012)
Tomato	Juice	30 kV cm; 0 to 45 min; <35 °C	Carvacrol (1.3 mM)	The simultaneous application of PEF and carvacrol caused the inactivation of *E. coli* O157:H7 by 5 log CFU/mL.	Ait-Ouazzou and others (2013)
			High hydrostatic pressure		
Apple	Juice	300 to 550 MPa or 300 MPa; 20 min; <30 °C	Essential oils (200 μL/L) and (+)-limonene (0 to 200 μL/L)	The combination of HHP (300 MPa for 20 min) with 200 μL/L of (+)-limonene achieved a 5 log reduction of *E. coli* O157:H7 concentration.	Espina et al. (2013)
Apple	Juice	100 to 500 MPa; 5 min; 50 °C	Lysozyme (0.05 and 0.1 mg/mL)	Lysozyme did not enhance the pressure effectiveness towards *Al. acidoterrestris* (TO-29/4/02) spores.	Sokołowska and others (2012)
Mango, orange, papaya	Juice blend	300 to 500 MPa; 5 to 15 min; <32 °C	*Stevia rebaudiana* Bertoni (0–2.5% w/v)	The optimal conditions of HPP were as follows: 1.7% of Stevia, 300 MPa/14 min. Under such conditions the greatest retention of bioactive compounds, antioxidant capacity as well as physicochemical properties were achieved.	Carbonell-Capella and others (2013)
Orange	Juice	300 to 550 MPa or 300 MPa; 20 min; <30 °C	Essential oils (200 μL/L) and (+) limonene (0 to 200 μL/L)	The combination of HHP (300 MPa/20 min) with 200 μL/L of (+)-limonene achieved a 5 log reduction in the initial *E. coli* O157:H7 concentration.	Espina et al. (2013)
Prickly pear	Juice	400 and 550 MPa; 0 to 16 min; 25 °C	Sodium benzoate (0.3 g/L), sodium sorbate (0.15 g/L), fumaric acid (1.4 g/L), tartaric acid (0.4 g/L) and sodium citrate (0.3 g/L)	Juice prepared from Cristal and Rojo San Martin varieties processed at 550 MPa/2 min showed significant increase in total phenolic (16% to 35%) and antioxidant activity (8% to 17%) and 3% to 15% losses of ascorbic acid. Juices formulated from the Rojo San Martin variety treated at 550 MPa/2 min showed significant increase in betaxanthins (6% to 8%) and betacyanin (4% to 7%).	Jiménez-Aguilar and others (2015)
			High-pressure homogenization		
Apple	Juice	20 MPa	D-Limonene (900 ppm) and citrus extract (2 ppm)	Citrus extract was able to control *S. bayanus* (DSMZ 70547) growth for 4 to 8 d. The use of limonene was not advisable for its strong organoleptic impact.	Bevilacqua and others (2012b)
Apple	Juice	140 MPa; ~40 °C	Sodium benzoate (80 mg/L)	1 to 2 log reduction for *Al. acidoterrestris* (DSMZ 2498). The additive effect for the combination benzoate + HPH was not recovered for the strain *Al. acidoterrestris* γ 4.	Bevilacqua and others (2012c)
Apricot	Juice	100 MPa; <40 °C	Citral (50 mg/L) and/or ethanol (1%, v/v)	After 8 passes at 100 MPa, a residual level of *S. cerevisiae* SPA of 1.2, 0.5, and 0.3 log CFU/mL was detected in the controls, samples supplemented with ethanol and samples with citral and ethanol, respectively.	Patrignani and others (2013)
Pineapple	Juice	120 and 150 MPa	Sodium benzoate (0 to 100 mg/L) and citrus extract (0 to 2000 mg/L)	The use of Na-benzoate and citrus extract strengthened the effect of HPH and reduced *F. oxysporum* (DSMZ 2018) spores below the detection limit immediately after homogenization.	Bevilacqua and others (2012a)
			ULTRA HIGH PRESSURE HOMOGENIZATION		
White mulberry	Juice	200 MPa; <35 °C	Dimethyl dicarbonate (250 mg/L)	The combined treatment with 3 passes of UHPH decreased the population of surviving indigenous microorganisms to the level attained by heat treatment with no significant increase in the population of microorganisms during the storage at 4 °C. High degree of retention in total phenolics, and α-glucosidase inhibitory activity. High losses in cyanidin 3-glucoside, cyanidin 3rutinoside, and antioxidant capacity.	Yu and others (2016)

(*Continued*)

Table 13–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Antimicrobial(s)	Key finding(s)	Reference
			Sonication		
Apple	Juice	600 W; 28 to 100 kHz; 0 to 50 min	Sodium benzoate (1000 ppm), potassium sorbate (1000 ppm), mixture of sodium benzoate and potassium sorbate (500 ppm each), α-pinene (60 ppm), β-pinene (60 ppm); mixture of α-pinene and β-pinene (30 ppm each).	Supplementation with 1000 ppm benzoate resulted in the significantly greatest inactivation of *E. coli* O157:H7.	Gabriel (2015)
Blueberry, orange, pomegranate	Juice blend	130 W; 20 kHz; 20 to 60%; 2 to 6 min; <40 °C	Citrus extract (50 and 100 ppm)	US reduced the initial contamination of *Z. bailii* (DSMZ 70492), whereas citrus extract could control the yeast within the storage. In this respect, citrus extract at 100 ppm was able to control *Z. bailii* for at least 6 d.	Bevilacqua and others (2014)
Grape	Wine	40 kHz; 10 and 20 min	SO_2 (40 mg/L)	97.45% and 98.04 *S. cerevisiae* (QA23) cells lethal rate after 10 and 20 min, respectively.	Cui and others (2012)
Kiwifruit	Juice	180 W; 40 kHz; 10 and 30 min; ~20 °C	Pomegranate extract (180 μg/mL)	The combinations of ultrasonic treatment with the application of pomegranate extract showed significant reductions on yeasts and molds counts with respect to untreated sample (1.46 and 2.13 log reductions after 10 and 30 min US treatment, respectively).	Tomadoni and others (2017)
Orange	Juice	130 W; 20 to 80%; 20 kHz; 2 to 8 min	Sodium benzoate (0 to 150 ppm) and citrus extract (0 to 1.800 ppm)	The use of benzoate and citrus extract achieved a reduction of 5 log of *F. oxysporum* (DSMZ 2018) spores for at least 14 ds of storage at 25 °C.	Bevilacqua and others (2013)
Orange	Juice	100 W; 20 kHz; 50%; 15 min; <30 °C	Crude extract of orange peel essential oils (250 μL/mL)	5 log reduction of natural occurring microorganisms.	Khandpur and Gogate (2016)
Orange	Juice	600 W; 28 to 100 kHz; 0 to 40 min	Sodium benzoate (1000 ppm), potassium sorbate (1000 ppm), mixture of sodium benzoate and potassium sorbate (500 ppm each), α-pinene (60 ppm), β-pinene (60 ppm); mixture of α-pinene and β-pinene (30 ppm each)	Supplementation with 1000 ppm benzoate resulted in the highest inactivation of *E. coli* O157:H7.	Gabriel (2015)
Pineapple	Juice	130 W; 0 to 80%; 20 kHz; 4 min	Sodium benzoate (0 to 200 ppm) + citrus extract (0 to 50 ppm)	The combination of US with antimicrobials cause a viability loss of *W. anomalus* (DSM 70130), which was reduced below the detection limit after 4 d at 25 °C. No significant effect on overall acceptability of juice.	Bevilacqua and others (2015)
Strawberry	Juice	180 W; 40 kHz; 0 to 30 min; ~20 °C	Vanillin (0 to 1.25 mg/mL) and pomegranate extract (0 to 360 μg/mL)	The optimal conditions to simultaneously minimize native microflora, maximize nutritional parameters and minimize the impact on sensory quality were 7.5 min of ultrasound treatment, pomegranate extract concentration of 360 μg/mL and vanillin concentration of 0.925 mg/mL.	Tomadoni and others (2016)
Strawberry	Fiber-enriched juice	180 W;40 kHz; 0 to 30 min; ~20 °C	Vanillin (0 to 1.25 mg/mL)	Juice treated under optimal conditions (1.25 mg/mL of vanillin, 7.5 min of ultrasound time and 5:3 of inulin:oligofructose proportion) resulted with enhanced microbial and sensory attributes.	Cassani and others (2017)
			Thermosonication		
Orange	Juice	24 KHz; 105 μm; 30 min; 50 °C	Cinnamon leaf essential oil (0.02mg/mL)	*S. cerevisiae* was reduced by 2.52 log CFU/mL. During refrigerated storage (5 °C, 28 d), *S. cerevisiae* population was reduced by 0.68 lo CFU/mL.	Sánchez-Rubio and others (2016)

(*Continued*)

Table 13–Continued.

Fruit/vegetable source(s)	Product	Processing conditions	Antimicrobial(s)	Key finding(s)	Reference
Pomegranate	Juice	24 KHz; 105 μm; 30 min; 50 °C	Cinnamon leaf essential oil (0.02mg/mL)	*S. cerevisiae* was reduced by 2.81 log CFU/mL. During refrigerated storage (5 °C, 28 d), *S. cerevisiae* population was reduced by 1.55 log CFU/mL.	Sánchez-Rubio and others (2016)
			Ultraviolet light		
Apple	Juice	254 nm; 0 to 3.58 min	Dimethyl dicarbonate (25 to 75 mg/L)	Up to 2.9 log-inactivation of *E. coli* (STCC 4201). The addition of dimethyl dicarbonate synergistically increased the lethality of UV radiation, mainly when the concentration was higher than 25 mg/L.	Gouma and others (2015b)
Apple	Juice	254 nm; 14.2 mJ/cm^2	Antifungal protein YvgO (N.I)	Microbial reduction of 6.74 and 0.50 log CFU/mL for *E. coli* (ATCC 25922) and spores of *Byssochlamys fulva* (H25), respectively.	Manns and others (2015)
Apple	Juice	254 nm; 14 mJ/cm^2	Ascorbic acid (0 to 600 mg/kg), potassium sorbate (0 to 200 mg/kg), sodium benzoate (0 to 1000 mg/kg), or sulfur dioxide (0 to 280 mg/kg)	The addition of ascorbic acid, sorbate, and benzoate significantly increased juices' absorption coefficients, which caused a reduction in the juice flow rate required to achieve the fixed UV dose. Increases in ascorbic acid concentration decreased inactivation of *E. coli* ATCC 25922.	Usaga and others (2017)
Apple	Cider	254 nm; 14.2 mJ/cm^2	Antifungal protein YvgO (N.I.)	Total inactivation of *E. coli* (ATCC 25922) (for example, 7.19 log reduction). *Byssochlamys fulva* (H25) spores were reduced only by 0.49 log CFU/mL.	Manns and others (2015)
Peach	Nectar	203 kJ/m^2; 254 nm; 0 to 60 min; ~25 °C	Potassium sorbate (250 to 2000 ppm) and sodium benzoate (250 to 1000 ppm)	Inactivation effectiveness decreased with increasing potassium sorbate concentration. The highest microbial inactivation (up to 5 log cycles) was achieved for *A. flavus* during the combined UV-sodium benzoate treatments, which also exhibited nectar microbial stability up to 15 ds at 25 °C.	Flores-Cervantes and others (2013)
Pineapple	Juice	10.76 mJ/cm^2	Dimethyl dicarbonate (250 ppm)	Post addition of dimethyl dicarbonate into the UV irradiated juice showed reductions of 2.61 log for total plate count and 4.87 log for yeasts and molds. Dimethyl dicarbonate did not cause any negative effect (apart from the total phenolic content) in the juice.	Shamsudin and others (2014)
Pitahaya	Juice	254 nm	Citric acid (0.5% to 2.0%) and dimethyl dicarbonate (5 to 20 μL/100 mL)	Addition of the citric acid and dimethyl dicarbonate to juice reduced the microbial loads, with 1.5% citric acid and 15 μL/100 mL dimethyl dicarbonate being the most effective concentrations.	Halim and others (2012)
			Gamma irradiation		
Sugarcane	Juice	5 kGy; ~26 °C	Citric acid (0.3%), sodium benzoate (0.015%), potassium sorbate (0.025%), and sucrose (10%).	The treatment prolonged the shelf life to 15 d at ambient temperature and 35 d at 10 °C.	Mishra and others (2011)
			Dense-phase carbon dioxide		
Orange	Juice	20 to 30 MPa; 10 to 70 min; 40 to 55 °C	Ethanol (1% to 5%, v/v)	97% reduction of PME with 2% DPCD.	Iftikhar and others (2014)

Table 14–Improving the effectiveness of nonthermal treatments—Approach 6: Combination with bacteriocins.

Fruit/vegetable source	Product	Processing conditions	Bacteriocin(s)	Key finding(s)	Reference
			Pulsed electric fields		
Apple	Juice	150 Hz; 35 kV/cm; 4 μs; 100 to 1000 μs; 20 °C	Enterocin AS-48 (0.175 to 1.05 AU/mL)	0.613 AU/mL of enterocin in combination with treatment time of 1000 μs reduced the population of *Pd. parvulus* (strain 48) by 6.6 log CFU/mL and yielded an apple juice that was free from pediococci during a 30 d storage period at 4 and 22°C.	Viedma and others (2010)
Orange	Juice	15 Hz; 40 kV/cm; 1 μs; 100 μs; <56 °C	Nisin (2.5 ppm) and natamycin (10 ppm)	Nisin combined with PEF inactivated *L. innocua* (IMD 1128) and *E. coli* k12 in a synergistic manner resulting in a total reduction to 5.6 and 7.9 log CFU/mL, respectively. The natamycin-PEF combination against *P. fermentans* (CBS189) was not significantly different to the effect caused by PEF alone.	McNamee and others (2010)
			High hydrostatic pressure		
Apple	Juice	100 to 500 MPa; 5 min; 50 °C	Nisin (500 to 1000 IU/mL)	Using pressure of 200 MPa for 45 min with a nisin concentration of 250 IU/mL enabled total *Al. acidoterrestris* (TO-29/4/02) spore inactivation.	Sokołowska and others (2012)
Cucumber	Juice	400 MPa; 4 min and 500 MPa; 2 min; ~25 °C	Nisin (100 IU/mL)	The samples treated by 500 MPa/2 min with nisin exhibited a longer shelf life under refrigerated conditions.	Zhao and others (2013)
			Dense-phase carbon dioxide		
Carrot	Juice	5 and 8 MPa; 25 to 45 °C/5 to 65 min	Nisin (200 IU/mL)	DPCD enhanced the sensitization of *E. coli* O157:H7 to nisin and the time for the complete inactivation was shortened by 2.5 to 5 min by combination of DPCD and nisin than by DPCD alone.	Bi and others (2014)
Litchi	Juice	10 MPa; 5 to 30 min; 32 to 52 °C	Nisin (200 ppm)	Complete inactivation of aerobic bacteria. No significant effect of nisin on the inactivation of yeasts and molds.	Li and others (2012)

the spore reduction was 2.4, 3.3, and 4.0 log CFU/mL, respectively for TO-29/4/02 strain, and 1.3, 2.6, and 2.8 log CFU/mL for TO-117/02 strain. Lee and others (2014) reported that when 10 kGy γ-irradiation was applied to apple juice, populations of *Al. acidoterrestris* spores were reduced by 4.34, 3.9, and 3.84 log cfu/mL in 18, 36, and 72 °Brix apple juice concentrates, respectively. When 10 kGy γ-irradiation was applied to 11 °Brix orange juice, populations of *Al. acidoterrestris* spores were reduced by 5 log CFU/mL; the reduction of spores in 33 and 66 °Brix orange juice concentrates exposed to 10-kGy γ-irradiation was 4.54 and 3.85 log.

The destruction pattern in different nonthermal technologies was found to be also dependent on pH. In HHP processing of carrot juice, a lower pH enhanced the death rate of *Bacillus licheniformis* spores (Tola and Ramaswamy 2014). Navarro and others (2014) demonstrated that the inactivation of PME in citrus juices by HPH at 150 MPa might be promoted by a low pH. Song and others (2015a) found that ozone treatment of pH 3.0 apple juice resulted in >5.36 log reduction *of E. coli* O157:H7; ozone treatment of pH 4.0 and 5.0 apple juice reduced this pathogen by 5.12 and 1.86 log CFU/mL, respectively.

Combination with heat

Electrical technologies can be effectively combined with temperature treatments. PEF treatments conducted at 55 °C significantly inhibited the growth of total aerobic bacteria in pomegranate juice, which remained <2.5 log CFU/mL during a 12-wk storage at 4 °C (Guo and others 2014). RFEF treatment conducted at 75 °C achieved a viability loss for *E. coli* K12 in apple juice by ca. 7 log CFU/mL (Ukuku and others 2012).

High-pressure processing is another nonthermal technology that can be successful combined with heat. Evelyn and others (2016) found that HPP-75 °C process was the most effective technique for inactivating *Neosartorya fischeri* ascospores in apple juice. In the same way, HHP-600 MPa/50 °C reduced by 3 log CFU/mL *Al. acidoterrestris* in orange juice (Hartyáni and others 2013). Pulsed HHP-50 °C reduced patulin in apple juice up to 45.49% (Avsaroglu and others 2015). HPH-68 °C preserved acceptability and cloudiness of orange juice for at least 3 m of refrigerated storage at 3 °C even with a high residual PME activity (75%; Carbonell and others 2013). UHPH (74.2 °C, maximum temperature) achieved the total inactivation in grape juice of *Salmonella enterica* serovar Senftenberg 775W (Velázquez-Estrada and others 2011).

Many authors stated that sonication is more effective than the treatment alone for microbial inactivation when combined with moderate heat (thermosonication, TS) or moderate heat and pressure (manothermosonication, MTS; Jiménez-Sánchez and others 2017a). Moody and others (2014) reported a 6 log reduction of *E. coli* after 5 min TS in apple juice when temperature was kept at 60 °C (Moody and others 2014). In orange juice, MTS treatments are highly effective on inactivating *L. monocytogenes* and *E. coli* (Guzel and others 2014).

Some published data demonstrated that it was difficult to guarantee the effectiveness of UV technology to reach 5 log-inactivation in fruit juices with high absorption coefficients and turbidities (Gayán and others 2012). One promising alternative to overcome these limitations is to combine UV light with mild conventional preservation methods (Gouma and others 2015a). UV-55 °C assured a 5 log-reduction of *E. coli* in apple and orange juices without affecting pH, soluble solids, and acidity (Gayán and others 2012, 2013).

A number of studies also focused on the combination of inert gas processing with heat. In apple juice, the aerobic bacteria were almost totally inactivated by DPCD at ≥52 °C (Liao and others 2010b). In strawberry juice, the highest level of POD inactivation (95%) was achieved at a temperature of 65 °C (Marszałek and others 2015b). The combination of ozone and heat for 1 min reduced *E. coli* O157:H7 in apple juice by 1.50 and 1.60 log CFU/mL, respectively, at 25 and 45 °C, and below the detection limit at 50 and 55 °C (Sung and others 2014).

Application of heat before or after nonthermal process

The use of nonthermal treatments in combination with heat can be approached also by a second strategy: namely, applying nonthermal treatments before or after heating of the food medium. An example was provided by Engmann and others (2014b). These authors first introduced mulberry juice into a hot water bath and then performed HHP. In another study, Yu and Rupasinghe (2013) first homogenized carrot juice under 100 MPa at 20 °C and then pasteurized at ~98 °C/3 min. As a result, a low sediment for 2 wk under refrigeration was found.

Tribst and others (2011) combined UHPH with a posterior heat shock to inactivate heat-resistant *Aspergillus niger* in mango nectar. The combined treatment reduced mold growth by 5 log CFU/mL, with a synergistic effect as compared to thermal treatment and HPH alone.

Evelyn and others (2016) thermally processed apple juice inoculated with *N. fischeri* in a water bath. This heat shock process might break the dormant state of mold spores and increase the number of spores able to germinate, leading to a loss of stability during the transition to the germinating stage. Then, TMS treatments were carried out in the thermostatic water bath inside the laminar flow hood. As a result, spores are more sensitive to the ultrasound + heat than heat alone.

Sew and others (2014) treated pineapple juice with mild heat followed by UV light at different dosages. Treating pineapple juice with mild heat at 55 °C for 10 min and UV decreased PME by 60.53% while retaining ~61.57% and 72.80% of bromelain and total phenolic content, respectively.

Parker and others (2010) combined γ-irradiation and heat treatments to inactivate *L. innocua* and *Clostridium sporogenes* in papaya nectar; the treated juice showed flavor and a nutritional profile close to untreated controls. In another study, a short thermal treatment was given to ginger and Indian borage ready-to-drink beverages, and the juices were then gamma irradiated; with 2 to 3 kGy dose, beverages remained microbiologically safe (Dadasaheb and others 2015).

Zhao and others (2014) first clarified apple juice by UF and then flash pasteurized. Under these conditions, total plate count and yeasts and molds were <1 log CFU/mL (Zhao and others 2014). The same approach was used to treat pear juice; total plate count and yeasts and molds were reduced below the detection level (Zhao and others 2016).

Combined technologies

The success of hurdle technologies largely depends on the compatibility of the components involved in each method and the ease with which each method can be implemented by the food industry (Martín-Belloso and Sobrino-López 2011).

PEF is a nonthermal technology that can be succesfully combined with other nonthermal processing techniques. Palgan and others (2012) studied the inactivation of *L. innocua* in a milk-based smoothie using PEF and MTS. As a result, the combination

achieved inactivation levels comparable to thermally treated samples (for example, 4.2 to 5.6 log CFU/mL). Caminiti and others (2012) combined PEF and MTS in carrot/orange juice blend processing; they found 19% PME residual activity. Caminiti and others (2011a) found that PEF in combination with UV or PL might maintain quality attributes of apple/cranberry juice blend (Caminiti and others 2011a). Aadil and others (2015a) evaluated the combined effects of PEF and US on some quality parameters of grapefruit juice. No significant change was observed in pH, acidity, °Brix and electrical conductivity; however, a significant decrease in viscosity and increase in cloudiness was observed after the combined treatment.

Another approach to overcome the limitations of radiation technology is to combine it with other nonthermal preservation methods. Ukuku and Geveke (2010) investigated a combined treatment of UV light and RFEF for the inactivation of *E. coli* K-12 in apple juice. The effect of the combination UV+RFEF was related to the temperature, as the viable count was reduced by 4 log CFU/mL at 25 °C and 5.5 log CFU/mL at 40 °C and at higher temperatures the extent of sub-lethal injury on cells was stronger. Khandpur and Gogate (2015) combined UV light and US in carrot, orange, spinach, and sweet lime juices, and found high retention of phenolic content and antioxidant activity as well as the free radical scavenging activity. Başlar and Ertugay (2013) used UV and TS in apple juice. This combination achieved 89.3% PPO enzyme inactivation, as well as an increase in color parameters. Ferrario and others (2015) evaluated the effect of PL and US on the inactivation of *Al. acidoterrestris* spores and *S. cerevisiae* inoculated in commercial and natural squeezed apple juices. The combination of these technologies led up to 3.0 log-reduction of spores in commercial apple juice and 2.0 log CFU/mL in natural juice, respectively; whereas for *S. cerevisiae* was reduced by 6.4 and 5.8 log CFU/mL. Muñoz and others (2011) combined PL and TS in orange juice obtaining 2.5 to 3.93 log inactivation of *E. coli* K12.

In recent years, an approach that has been explored to overcome bacterial pressure resistance is the combination of HP technology with other nonthermal treatments (Feyaerts and others 2015). Abid and others (2014) combined HHP and US for apple juice processing. The combination US-pressure at 450 MPa led to the highest inactivation of PME, PPO, and POD, the complete inactivation of total plate counts, yeasts and molds, as well as a significant improvement of phenolic compounds, ascorbic acid, antioxidant capacity, radical scavenging activity and color values. Evelyn and Silva (2016) used HHP to enhance spore inactivation of *Al. acidoterrestris* in orange juice by TS. Shahbaz and others (2016) reported that *L. monocytogenes* and *S. aureus* were completely inactivated when treated with a combination of HHP and TUVP. In a prebiotic cranberry juice fortified with FOS the retention of organic acids was high (>90%) and an increase in anthocyanin content (up to 24%) was observed when US was followed by HPP (Gomes and others 2017).

The use of DPCD in combination with US is a relatively new concept. Ortuño and others (2014b) proposed this approach using US embedded in a DPCD system for the inactivation kinetics of *E. coli* and *S. cerevisiae* cells in apple juice. Treatment totally inactivated the population of *E. coli* and *S. cerevisiae*. In another study, Ortuño and others (2014a) used the combination of US + DPCD to inactivate *E. coli* and *S. cerevisiae* in orange juice. Cappelletti and others (2014) used DPCD + US in coconut water, and achieved a 5 log reduction of the natural microbiota in 15 min whereas 30 min were required for DPCD treatment alone. The shelf life was ca. 4 wk at 4 °C.

Another interesting possibility is the combination of membrane processing with other nonthermal treatments. During the FO concentration of fruit juices, as water permeates through the membrane, pectin present in the juice accumulates on the membrane surface and forms a thick layer leading to the advent of cake-enhanced concentration polarization that reduces the net driving force. In this respect, the application of external fields such as US is expected to mitigate the concentration polarization resulting in higher flux rates (Chanukya and Rastogi, 2017). Zhao and others (2015a) combined MF and UV achieving more than a 5 log reduction of *E. coli*, *Cryptosporidium parvum*, and *Al. acidoterrestris* in apple cider. Zhao and others (2014) found that fresh apple juice processed by UF + HPP was microbiologically safe during subsequent 60 d of storage at 4 °C. Zhao and others (2016) combined UF + HHP for pear juice processing. During 56 d of refrigerated storage, all samples showed microbial safety, as well as low decrease in total phenols and antioxidant capacity.

Onsekizoglu and others (2010) combined UF + OD and/or MD. This new membrane-based concentration techniques were very efficient since the product characteristics were very similar to that of the initial apple juice especially regarding the retention of bright natural color and pleasant aroma, which are significantly lost during thermal evaporation. Sagu and others (2014b) combined UF + MF for banana juice processing. The storage study indicated that the juice could be successfully stored for 1 mo at 4 °C without any additive and preservative, keeping its natural nutritional qualities, taste, and flavor intact. Souza and others (2013) used integrated membrane processes (RO + OD) reaching concentration levels up to 7 times for camu-camu juice's bioactive compounds (Souza and others 2013). In another study, integrated membrane techniques (UF + OD and/or MD) were very efficient to maintaining the original characteristics of the clarified pomegranate juice (Onsekizoglu 2013). MD + OD membrane systems was more advantageous comparing to the conventional method in terms of the formation of hydroxymethylfurfural and furan in tomato juice (Savaş Bahçeci and others 2015).

A recent interesting possibility is the combination of nonthermal treatments with alternative thermal technologies. Lee and others (2013b) obtained about 6.30 log reduction of *E. coli* for apple juice treated with the UV/OH combination at 65 °C (OH, ohmic heating). Samani and others (2015a) combined US and MW in orange juice processing. Park and others (2013) combined HHP + OH for tomato juice processing. As a result, *B. amyloliquefaciens* and *Geobacillus stearothermophilus* spores were reduced by 3.1 and 4.8 log CFU/mL, respectively.

Combination with antimicrobials

Apart from thermal pasteurization, some chemical preservatives are also widely used for the extension of the shelf life of juices and beverages. Two of the most commonly used preservatives are potassium sorbate and sodium benzoate. Nitrate and nitrite as sodium or potassium salts has also been used as food additives to improve the microbiological safety of food and to extend their safe shelf life (Backialakshmi and others 2015). Combining nonthermal technologies with other mode of preservation such as antimicrobial agents has recently been successfully used to keep food safety and quality of fruit and vegetable juices (Table 13).

A study performed on strawberry juice inoculated with *E. coli* and treated with PEF in combination with sodium benzoate, potassium sorbate and citric acid, showed a reduction of 5.11 log CFU/mL on the microbial count after exposure to PEF, whereas in

the sample without preservatives, a decrease of 3.79 log CFU/mL was achieved (Gurtler and others 2011).

Another approach relies upon the use of antimicrobials in combination with HP treatment. Studies on a wide range of vegetative bacteria and both in buffer and foods have found that antimicrobials can considerably enhance bacterial inactivation by HP treatment, even when they are used at sublethal concentrations (Feyaerts and others 2015). Espina and others (2013) tested the combination of HHP with (+)-limonene achieving up to a 5 log reduction in the initial *E. coli* concentration in apple and orange juices. In another study, Carbonell-Capella and others (2013) evaluated the combination of HHP + *Stevia rebaudiana* Bertoni in mango/orange/papaya juice blend.

Bevilacqua and others (2012b) used HPH to process an apple juice supplemented with natural antimicrobials such as limonene and citrus extract as hurdles against *S. bayanus* growth. HPH at 20 MPa reduced the colony count of *S. bayanus* by 2 to 4 log CFU/mL; citrus extract supplementation delayed the growth of the yeast for 4 to 8 d at 25 °C.

Efficiency of combined application of US technology and antimicrobials has been successfully studied for many fruit juices. In pineapple juice, the combination of US with sodium benzoate + citrus extract caused a viability loss of *Wickerhamomyces anomalus*, which was reduced below the detection limit after 4 d at 25 °C; the treatment has no significant effect on overall acceptability of product (Bevilacqua and others 2015). In orange juice, the use of benzoate and citrus extract achieved a reduction of 5 log CFU/mL of *Fusarium oxysporum* spores for at least 14 d of storage at 25 °C (Bevilacqua and others 2013). In blueberry/orange/pomegranate juice blend, US reduced the initial contamination of *Z. bailii* whereas citrus extract could control the yeast within the storage. In this respect, citrus extract at 100 ppm was able to control *Z. bailii* for at least 6 d at 25 °C (Bevilacqua and others 2014).

Despite the benefits of UV nonthermal treatment for food decontamination, the potential reactivation of pathogenic bacteria after exposure to UV light should not be ignored. Bacteria generally possess molecular mechanisms to compensate for the damaging effects of UV light radiation on DNA (Yin and others 2015). To overcome this limitation, the hurdle technology might be useful. For example, post addition of dimethyl dicarbonate into the UV-treated pineapple juice has been found to reduce by 2.61 and 4.87 log CFU/mL, respectively, total plate count and yeasts and molds; dimethyl dicarbonate did not cause any negative effect (apart from the total phenolic content) in the juice (Shamsudin and others 2014). Similarly, the addition of dimethyl dicarbonate to apple juice synergistically increased the lethality of UV radiation, mainly when the concentration was higher than 25 mg/L (Gouma and others 2015b). However, although the addition of certain additives represents a viable option to ensure the safety and extend the shelf life of UV-treated beverages, Usaga and others (2017) reported that ascorbic acid, benzoate, and sorbate, additives commonly used by the juice industry, increased apple juice's absorption coefficient and negatively interfere with the performance of UV.

Combining γ-irradiation technology with antimicrobial compounds has also been evaluated. Mishra and others (2011) tested the combination of citric acid, sodium benzoate, potassium sorbate, and sucrose for extending the shelf life of gamma irradiated sugarcane juice to 15 d at ambient temperature and 35 d at 10 °C. The microbial load was found to be below detectable limit within this period with any effect on the quality parameters. In addition, the sensory evaluation scores showed that the juice with this combination treatment was highly acceptable.

With regard to inert gas processing, the addition of ethanol to orange juice processed by DPCD proved to be effective as 97% PME inactivation was achieved at the level of 2% (v/v; Iftikhar and others 2014).

Combination with bacteriocins

Bacteriocins could also be applied in combination with nonthermal food processing technologies in order to increase the efficacy of treatments and protect against proliferation of survivors during storage.

McNamee and others (2010) incorporated nisin and natamycin in orange juice processed by PEF technology in order to inactivate spoilage (*P. fermentans*) and pathogenic (*E. coli* and *Listeria* spp.) microorganisms. Combinations of nisin and PEF showed the most synergistic effect on inactivation levels, producing a reduction of up to 5 log CFU/mL or more in all the microorganisms studied. Viedma and others (2010) tested Enterocin AS-48 in combination with PEF for reducing the population of *Pd. parvulus* by 6.6 log CFU/mL and yielded an apple juice that was free from pediococci during a 30-d storage period at 4 and 22 °C.

Sokołowska and others (2012) used HHP with nisin to total inactivate *Al. acidoterrestris* spores (over 6 log) in apple juice. Zhao and others (2013) treated cucumber juice by HHP with nisin, thus obtaining a longer shelf life under refrigerated conditions as compared with other treated samples.

Li and others (2012) evaluated the combination DPCD + nisin in litchi juice. As a result, the complete inactivation of aerobic bacteria was achieved; however, no significant effect of nisin was found on the inactivation of yeasts and molds. In another study, Bi and others (2014) combined DPCD and nisin to inactivate *E. coli* in carrot juice. DPCD enhanced the sensitization of *E. coli* to nisin and the time for the complete inactivation was shortened by 2.5 to 5 min.

Conclusions: To be Continued

Heat treatments still remain the most used approach to assure quality and safety of juices and beverages; however, they might have some detrimental effects on the nutritional quality negatively impact on the fresh-like characteristics. A possibility is the use of nonthermal approach. This paper offers on overview of the most recent advances (5 to 10 y) in terms of process design and optimization for pressure, electrical light, radiation, membrane and gas based-approach, with a special focus on the retention of bioactive compounds, inactivation of enzymes and spoiling microorganisms as well as pathogens.

For each approach, the focus is on the effective conditions of processing, as well as on some indices related to treatment effectiveness, focusing on different juices and products. Some approaches are currently used for industrial applications (for example, high pressure, homogenization), while others are still at laboratory level, and many times the scale up is a critical step. Therefore, further efforts are required to implement these methodologies and combine the desire of an increased nutritional quality and the economicity of the process, as the high cost is still a drawback and limits the diffusion of these approaches. A never-ending story to be continued.

Abbreviations

DCEF	Direct current electric field
DCMD	Direct contact membrane distillation
DPCD	Dense phase carbon dioxide
EF	Electric field

EBI	Electron beam irradiation
FO	Forward osmosis
FOS	Fructo-oligosaccharides
GI	Gamma irradiation
HHP	High hydrostatic pressure
HMF	5-Hydroxymethyl-2-furfural
HPCD	High-pressure carbon dioxide
HPH	High-pressure homogenization
HVED	High-voltage electrical discarge
LCD	Liquid carbon dioxide
LOX	Lipoxygenase
MD	Membrane distillation
MF	Microfiltration
MS	Manosonication
MTS	Manothermosonication
MW	Microwave
MWCO	Molecular weight cut-off
NF	Nanofiltration
OD	Osmotic distillation
OH	Ohmic heating
OS	Osmosonication
p-HHP	Pulsed HHP
PCT	Pressure change technology
PE	Pectinesterase
PEF	Pulsed electric field
PG	Polygalacturonase
PL	Pulsed light
PM	Pervaporation membranes
PME	Pectin methyl esterase
POD	Peroxidase
PP	Polypropylene
PPO	Polyphenol oxidase
PRO	Proteolytic activity
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidenedifluoride
RFEF	Radio frequency electric fields
RO	Reverse osmosis
SCCD	Supercritical carbon dioxide
TS	Thermosonication
TUVP	Titanium dioxide-UVC photocatalysis
UF	Ultrafiltration
UHPH	Ultra-high-pressure homogenization
US	Ultrasound
UV	Ultraviolet
VMD	Vacuum membrane distillation

Abbreviations of microorganisms

Alicyclobacillus	*Al.*
Aspergillus	*A.*
Bacillus	*B.*
Brettanomyces	*Br.*
Citrobacter	*Cit.*
Clostridium	*Cl.*
Escherichia	*E.*
Fusarium	*F.*
Lactobacillus	*Lb.*
Listeria	*L.*
Neosartorya	*N.*
Oenococcus	*O.*
Pediococcus	*Pd.*
Pichia	*P.*
Pseudomonas	*Ps.*
Saccharomyces	*S.*
Staphylococcus	*Staph.*
Wickeramomyces	*W.*
Zygosaccharomyces	*Z.*

References

Aadil RM, Zeng XA, Sun DW, Wang MS, Liu ZW, Zhang ZH. 2015a. Combined effects of sonication and pulsed electric field on selected quality parameters of grapefruit juice. LWT - Food Sci Technol 62:890–3.

Aadil RM, Zeng XA, Wang MS, Liu ZW, Han Z, Zhang ZH, Hong J, Jabbar S. 2015b. A potential of ultrasound on minerals, micro-organisms, phenolic compounds and colouring pigments of grapefruit juice. Int J Food Sci Technol 50:1144–50.

Abdullah N, Chin NL. 2014. Application of thermosonication treatment in processing and production of high quality and safe-to-drink fruit juices. Agric Agric Sci Proc 2:320–7.

Abid M, Jabbar S, Hu B, Hashim MM, Wu T, Wu Z, Khan MA, Zeng X. 2014. Synergistic impact of sonication and high hydrostatic pressure on microbial and enzymatic inactivation of apple juice. LWT - Food Sci Technol 59:70–6.

Acosta O, Vaillant F, Pérez AM, Dornier M. 2014. Potential of ultrafiltration for separation and purification of ellagitannins in blackberry (*Rubus adenotrichus* Schltdl.) juice. Sep Purif Technol 125:120–5.

Acosta O, Vaillant F, Pérez AM, Dornier M. 2017. Concentration of polyphenolic compounds in blackberry (*Rubus adenotrichos* SchltdL.) juice by nanofiltration. J Food Process Eng 40: e12343.

Adekunte A, Tiwari BK, Scannell A, Cullen PJ, O'Donnell C. 2010. Modelling of yeast inactivation in sonicated tomato juice. Int J Food Microbiol 137:116–20.

Aganovic K, Grauwet T, Kebede BT, Toepfl S, Heinz V, Hendrickx M, Van Loey A. 2014. Impact of different large scale pasteurisation technologies and refrigerated storage on the headspace fingerprint of tomato juice. Innov Food Sci Emerg Technol 26:431–44.

Aganovic K, Grauwet T, Siemer C, Toepfl S, Heinz V, Hendrickx M, van Loey A. 2016. Headspace fingerprinting and sensory evaluation to discriminate between traditional and alternative pasteurization of watermelon juice. Eur Food Res Technol 242:787–803.

Ağçam E, Akyıldız A, Akdemir Evrendilek G. 2014. Effects of PEF and heat pasteurization on PME activity in orange juice with regard to a new inactivation kinetic model. Food Chem 165:70–6.

Aghdam MA, Mirsaeedghazi H, Aboonajmi M, Kianmehr MH. 2015. Effect of ultrasound on different mechanisms of fouling during membrane clarification of pomegranate juice. Innov Food Sci Emerg Technol 30:127–31.

Aguiar IB, Miranda NGM, Gomes FS, Santos MCS, DGC Freitas, Tonon RV, Cabral LMC. 2012. Physicochemical and sensory properties of apple juice concentrated by reverse osmosis and osmotic evaporation. Innov Food Sci Emerg Technol 16:137–42.

Aguilar K, Garvin A, Azuara E, Ibarz A. 2015. Modelling of 5-hydroxymethylfurfural photo-degradation by UV irradiation. Influence of temperature and pH. Food Res Int 71:165–73.

Aguilar K, Garvín A, Ibarz A, Augusto PED. 2017. Ascorbic acid stability in fruit juices during thermosonication. Ultrason Sonochem 37:375–81.

Aguiló-Aguayo I, Soliva-Fortuny R, Martín-Belloso O. 2010a. Color and viscosity of watermelon juice treated by high-intensity pulsed electric fields or heat. Innov Food Sci Emerg Technol 11:299–305.

Aguiló-Aguayo I, Soliva-Fortuny R, Martín-Belloso O. 2010b. High-intensity pulsed electric fields processing parameters affecting polyphenoloxidase activity of strawberry juice. J Food Sci 75:C641–C6.

Ait-Ouazzou A, Espina L, Garcia-Gonzalo D, Pagan R. 2013. Synergistic combination of physical treatments and carvacrol for *Escherichia coli* O157:H7 inactivation in apple, mango, orange, and tomato juices. Food Control 32:159–67.

Alexandrakis Z, Kyriakopoulou K, Katsaros G, Krokida M, Taoukis P. 2014. Selection of process conditions for high pressure pasteurization of sea buckthorn juice retaining high antioxidant activity. Food Bioprocess Technol 7:3226–34.

Alighourchi H, Barzegar M, Sahari, MA, Abbasi S. 2014. The effects of sonication and gamma irradiation on the inactivation of *Escherichia coli* and *Saccharomyces cerevisiae* in pomegranate juice. Iran J Microbiol 6:51–8.

Almeida FDL, Cavalcante RS, Cullen PJ, Frias JM, Bourke P, Fernandes FAN, Rodrigues S. 2015. Effects of atmospheric cold plasma and ozone on prebiotic orange juice. Innov Food Sci Emerg Technol 32:127–35.

Altuntas J, Evrendilek GA, Sangun MK, Zhang HQ. 2010. Effects of pulsed electric field processing on the quality and microbial inactivation of sour cherry juice. Int J Food Sci Technol 45:899–905.

Alves Filho EG, Almeida FDL, Cavalcante RS, de Brito ES, Cullen PJ, Frias JM, Bourke P, Fernandes FAN, Rodrigues, S. 2016. ^{1}H NMR spectroscopy and chemometrics evaluation of nonthermal processing of orange juice. Food Chem 204:102–7.

Amirasgari N, Mirsaeedghazi H. 2014. Microfiltration of red beet juice using mixed cellulose ester membrane. J Food Process Pres 39:614–23.

Anaya-Esparza LM, Velázquez-Estrada RM, Roig AX, García HS, Sayago-Ayerdi SG, Montalvo-González E. 2017. Thermosonication: an alternative processing for fruit and vegetable juices. Trends Food Sci Tech 61:26–37.

Andrés V, Mateo-Vivaracho LEG, MY V, Tenorio M. 2016a. High hydrostatic pressure treatment and storage of soy-smoothies: colour, bioactive compounds and antioxidant capacity. LWT - Food Sci Technol 69:123–30.

Andrés V, Villanueva MJ, Tenorio MD. 2016b. Influence of high pressure processing on microbial shelf life, sensory profile, soluble sugars, organic acids, and mineral content of milk- and soy-smoothies. LWT - Food Sci Technol 65:98–105.

Andrés V, Villanueva MJ, Tenorio MD. 2016c. The effect of high-pressure processing on colour, bioactive compounds, and antioxidant activity in smoothies during refrigerated storage. Food Chem 192:328–35.

Aneja KR, Dhiman R, Aggarwal NK, Aneja A. 2014. Emerging preservation techniques for controlling spoilage and pathogenic microorganisms in fruit juices. Int J Microbiol ID758942.

Arjeh E, Barzegar M, Ali Sahari M. 2015. Effects of gamma irradiation on physicochemical properties, antioxidant and microbial activities of sour cherry juice. Radiat Phys Chem 114:18–24.

Arriola NA, dos Santos GD, Prudêncio ES, Vitali L, Petrus JCC, Amboni RDMC. 2014. Potential of nanofiltration for the concentration of bioactive compounds from watermelon juice. Int J Food Sci Technol 49:2052–60.

Aschoff JK, Knoblauch K, Hüttner C, Vásquez-Caicedo AL, Carle R, Schweiggert RM. 2016. Non-thermal pasteurization of orange (*Citrus sinensis* (L.) Osbeck) juices using continuous pressure change technology (PCT): a proof-of-concept. Food Bioprocess Technol 9:1681–91.

Avsaroglu MD, Bozoglu F, Alpas H, Largeteauc AG, Demazeau G. 2015. Use of pulsed-high hydrostatic pressure treatment to decrease patulin in apple juice. High Press Res 35:214–22.

Awua AK, Doe ED, Agyare R. 2011. Exploring the influence of sterilisation and storage on some physicochemical properties of coconut (*Cocos nucifera* L.) water. Biomed Cent 4:451–9.

Azhuvalappil Z, Fan X, Geveke DJ, Zhang HQ. 2010. Thermal and nonthermal processing of apple cider: storage quality under equivalent process conditions. J Food Quality 33:612–31.

Backialakshmi S, Meenakshi RN, Saranya A, Jebil MS, Krishna AR, Krishna JS, Ramasamy S. 2015. Biopreservation of fresh orange juice using Antilisterial Bacteriocins101 and Antilisterial Bacteriocin103 purified from *Leuconostoc mesenteroides*. J Food Process Technol 6:479.

Baklouti S, Ellouze-Ghorbel R, Mokni A, Chaabouni S. 2012. Clarification of pomegranate juice by ultrafiltration: study of juice. Fruits 67:215–25.

Bansal V, Sharma A, Ghanshyam C, Singla ML, Kima K-H. 2015. Influence of pulsed electric field and heat treatment on *Emblica officinalis* juice inoculated with *Zygosaccharomyces bailii*. Food Bioprod Process 95:146–54.

Barba FJ, Cortés C, Esteve MJ, Frígola A. 2012a. Study of antioxidant capacity and quality parameters in an orange juice–milk beverage after high-pressure processing treatment. Food Bioprocess Technol 5:2222–32.

Barba FJ, Esteve MJ, Frigola A. 2010. Ascorbic acid is the only bioactive that is better preserved by high hydrostatic pressure than by thermal treatment of a vegetable beverage. J Agr Food Chem 58:10070–5.

Barba FJ, Esteve MJ, Frigola A. 2013. Physicochemical and nutritional characteristics of blueberry juice after high pressure processing. Food Res Int 50:545–9.

Barba FJ, Jägerb H, Meneses N, Esteve MJ, Frígola A, Knorr D. 2012b. Evaluation of quality changes of blueberry juice during refrigerated storage after high-pressure and pulsed electric fields processing. Innov Food Sci Emerg Technol 14:18–24.

Başlar M, Ertugay MF. 2013. The effect of ultrasound and photosonication treatment on polyphenoloxidase (PPO) activity, total phenolic component and colour of apple juice. Int J Food Sci Technol 48:886–92.

Beaulieu JC, Stein-Chisholm RE, Lloyd SW, Bett-Garber KL, Grimm CC, Watson MA, Lea JM. 2016. Volatile, anthocyanidin, quality and sensory changes in rabbiteye blueberry from whole fruit through pilot plant juice processing. J Sci Food Agric 97:469–78.

Bélafi-Bakó K, Boór A, Nemestóthy N. 2012. Comparative study on concentration of juices from colourful wild berry fruits by membrane osmotic distillation. Hung J Ind Chem 40:53–6.

Belda-Galbis CM, Martínez A, Rodrigo D. 2016. Microbial inactivation in a non-commercial juice of mango and papaya submitted to pulsed electric fields in presence of a *Stevia rebaudiana* Bertoni extract. IFMBE Proc 53:119–23.

Bello EFT, González Martínez GG, Ceberio BFK, Rodrigo D, Martínez López A. 2014. High pressure treatment in foods. Foods 3:476–90.

Belloch C, Gurrea MC, Tárrega A, Sampedro F, Carbonell JV. 2012. Inactivation of microorganisms in orange juice by high-pressure homogenization combined with its inherent heating effect. Eur Food Res Technol 234:753–60.

Bermúdez-Aguirre D, Barbosa-Cánovas GV. 2012. Inactivation of *Saccharomyces cerevisiae* in pineapple, grape and cranberry juices under pulsed and continuous thermo-sonication treatments. J Food Eng 108:383–92.

Betoret E, Betoret N, Rocculi P, Dalla Rosa M. 2015. Strategies to improve food functionality: Structure–property relationships on high pressures homogenization, vacuum impregnation and drying technologies. Trends Food Sci Tech 46:1–12.

Betoret E, Mannozzi C, DellarosaN, Laghi L, Rocculi P, Dalla Rosa M. 2017. Metabolomic studies after high pressure homogenization processed low pulp mandarin juice with trehalose addition. Functional and technological properties. J Food Eng 200:22–8.

Bevilacqua A, Campaniello D, Sinigaglia M, Ciccarone C, Corbo MR. 2012a. Sodium-benzoate and citrus extract increase the effect of homogenization towards spores of *Fusarium oxysporum* in pineapple juice. Food Control 28:199–204.

Bevilacqua A, Campaniello D, Sinigaglia M, Corbo MR 2015. Combination of ultrasound and antimicrobial compounds towards *Pichia* spp. and *Wickerhamomyces anomalus* in pineapple juice. LWT - Food Sci Technol 64:616–22.

Bevilacqua A, Corbo MR, Sinigaglia M. 2012b. Use of natural antimicrobials and high pressure homogenization to control the growth of *Saccharomyces bayanus* in apple juice. Food Control 24:109–15.

Bevilacqua A, Corbo MR, Sinigaglia M. 2012c. High-pressure homogenisation and benzoate to control *Alicyclobacillus acidoterrestris*: a possible way?. Int J Food Sci Technol 47:879–83.

Bevilacqua A, Sinigaglia M, Corbo MR. 2013. Ultrasound and antimicrobial compounds: a suitable way to control *Fusarium oxysporum* in juices. Food Bioprocess Technol 6:1153–63.

Bevilacqua A, Speranza B, Campaniello D, Sinigaglia M, Corbo MR. 2014. Inactivation of spoiling yeasts of fruit juices by pulsed ultrasound. Food Bioprocess Technol 7:2189–97.

Bhat R, Ameran SB, Voon HC, Karim AA, Tze LM. 2011a. Quality attributes of starfruit (*Averrhoa carambola* L.) juice treated with ultraviolet radiation. Food Chem 127:641–4.

Bhat R, Kamaruddin NS, Min-Tze L, Karim AA. 2011b. Sonication improves kasturi lime (*Citrus microcarpa*) juice quality. Ultrason Sonochem 18:1295–300.

Bhat R, Stamminger R. 2015a. Preserving strawberry quality by employing novel food preservation and processing techniques – recent updates and future scope – an overview. J Food Process Eng 3:536–54.

Bhat R, Stamminger R. 2015b. Impact of ultraviolet radiation treatments on the physicochemical properties, antioxidants, enzyme activity and microbial load in freshly prepared hand pressed strawberry juice. Food Sci Technol Int 21:354–63.

Bhat S, Sharma HK. 2016. Combined effect of blanching and sonication on quality parameters of bottle gourd (*Lagenaria siceraria*) juice. Ultrason Sonochem 33:182–9.

Bhat S. 2016. Impact of ultraviolet radiation treatments on the quality of freshly prepared tomato (*Solanum lycopersicum*) juice. Food Chem 213:635–40.

Bi X, Liu F, Rao L, Li J, Liu B, Liao X, Wu J. 2013. Effects of electric field strength and pulse rise time on physicochemical and sensory properties of apple juice by pulsed electric field. Innov Food Sci Emerg Technol 17:85–92.

Bi X, Wang Y, Zhao F, Zhang Y, Rao L, Liao X, Hu X, Sun Z. 2014. Inactivation of *Escherichia coli* O157: H7 by high pressure carbon dioxide

combined with nisin in physiological saline, phosphate-buffered saline and carrot juice. Food Control 41:139–46.

Biswas PP, Mondal M, De S. 2016. Comparison between centrifugation and microfiltration as primary clarification of bottle gourd (*Lagenaria siceraria*) juice. J Food Process Pres 40:226–38.

Błaszczak W, Amarowicz R, Górecki AR. 2017. Antioxidant capacity, phenolic composition and microbial stability of aronia juice subjected to high hydrostatic pressure processing. Innov Food Sci Emerg Technol 39:141–7.

Buckow R, Kastell A, Terefe NS, Versteeg C. 2010. Pressure and temperature effects on degradation kinetics and storage stability of total anthocyanins in blueberry juice. J Agr Food Chem 58:10076–84.

Buckow R, Ng S, Toepfl S. 2013. Pulsed electric field processing of orange juice: a review on micronial, enzymatic, nutritional, and sensory quality and stability. Compr Rev Food Sci Food Saf 12:455–467.

Bule MV, Desai KM, Parulekar SJ, Slade P, Singhal RS, Rodriguez R. 2010. Furan formation during UV-treatment of fruit juices. Food Chem 13:937–42.

Buniowska M, Carbonell-Capella JM, Frígola A, Esteve Mas MJ. 2016. Steviol glycosides stability after pulsed electric technologies and ultrasounds treatments in fruit juice blend sweetened with stevia rebaudiana. IFMBE Proceedings 53:136–9.

Bursać Kovačević D, Gajdoš Kljusurić J, Putnik P, Vukušić T, Herceg Z, Verica Dragović-Uzelac V. 2016a. Stability of polyphenols in chokeberry juice treated with gas phase plasma. Food Chem 212:323–31.

Bursać Kovačević D, Putnik P, Dragović-Uzelac V, Pedisić S, Režek Jambrak A, Herceg Z. 2016b. Effects of cold atmospheric gas phase plasma on anthocyanins and color in pomegranate juice. Food Chem 190:317–23.

Calligaris S, Foschia M, Bartolomeoli I, Maifreni M, Manzocco L. 2012. Study on the applicability of high-pressure homogenization for the production of banana juices. LWT- Food Sci Technol 45:117–21.

Caminiti IM, Noci F, Morgan DJ, Cronin DA, Lyng JG. 2012. The effect of pulsed electric fields, ultraviolet light or high intensity light pulses in combination with manothermosonication on selected physico-chemical and sensory attributes of an orange and carrot juice blend. Food Bioprod Process 90:442–8.

Caminiti IM, Noci F, Munoz A, Whyte P, Morgan D Cronin DA. 2011a. Impact of selected combinations of non-thermal processing technologies on the quality of an apple and cranberry juice blend. J Food Chem 124:1387–9.

Caminiti IM, Palgan I, Noci F, Muñoz A, Whyte P, Cronin DA, Morgan DJ, Lyng JG. 2011b. The effect of pulsed electric fields (PEF) in combination with high intensity light pulses (HILP) on *Escherichia coli* inactivation and quality attributes in apple juice. Innov Food Sci Emerg Technol 12:118–23.

Campos PR, Módenes AN, Espinoza-Quiñones FR, Trigueros DE, Barros ST, Pereira NC 2016. Improvement on the concentrated grape juice physico-chemical characteristics by an enzymatic treatment and membrane separation processes. An Acad Bras Ciênc 88:423–36.

Cancino-Madariaga B, Ruby R, Astudillo Castro C, Saavedra Torrico J, Lutz Riquelme M. 2012. Analysis of the membrane fouling mechanisms involved in clarified grape juice ultrafiltration using statistical tools. Ind Eng Chem Res 51:4017–24.

Cao X, Bi X, Huang W, Wu J, Hu X, Liao X. 2012. Changes of quality of high hydrostatic pressure processed cloudy and clear strawberry juices during storage. Innov Food Sci Emerg Technol 16:181–90.

Cappelletti M, Ferrentino G, Endrizzi I, Aprea E, Betta E, Corollaro ML, Charles M, Gasperi F, Spilimbergo S. 2015. High pressure carbon dioxide pasteurization of coconut water: a sport drink with high nutritional and sensory quality. J Food Eng 145:73–81.

Cappelletti M, Ferrentino G, Spilimbergo S. 2014. Supercritical carbon dioxide combined with high power ultrasound: an effective method for the pasteurization of coconut water. J Supercrit Fluids 92:257–63.

Carbonell JV, Navarro JL, Izquierdo L, Sentandreu E. 2013. Influence of high pressure homogenization and pulp reduction on residual pectinmethylesterase activity, cloud stability and acceptability of Lane Late orange juice: a study to obtain high quality orange juice with extended shelf life. J Food Eng 119:696–700.

Carbonell-Capella JM, Barba FJ, Esteve MJ, Frígola A. 2013. High pressure processing of fruit juice mixture sweetened with *Stevia rebaudiana* Bertoni: Optimal retention of physical and nutritional quality. Innov Food Sci Emerg Technol 18:48–56.

Carbonell-Capella JM, Buniowska M, Barba FJ, Grimi N, Vorobiev E, Esteve MJ, Frígola A. 2016. Changes of antioxidant compounds in a fruit juice-*Stevia rebaudiana* blend processed by pulsed electric technologies and ultrasound. Food Bioprocess Technol 9:1159–68.

Carreño JM, Gurrea MC, Sampedro F, Carbonell JV. 2011. Effect of high hydrostatic pressure and high-pressure homogenisation on *Lactobacillus plantarum* inactivation kinetics and quality parameters of mandarin juice. Eur Food Res Technol 232:265–74.

Cassani L, Tomadoni B, Moreira MR, Ponce A, Agüero MV. 2017. Optimization of inulin: oligofructose proportion and non-thermal processing to enhance microbiological and sensory properties of fiber-enriched strawberry juice. LWT - Food Sci Technol 80:446–55.

Cassano A, Conidi C, Drioli E. 2010. Physico-chemical parameters of cactus pear (*Opuntia ficus-indica*) juice clarified by microfiltration and ultrafiltration processes. Desalin 250:1101–4.

Cassano A, Conidi C, Drioli E. 2011. Clarification and concentration of pomegranate juice (*Punica granatum L.*) using membrane processes. J Food Eng 107:366–73.

Cassano A, Conidi C, Drioli E. 2013. A membrane-based process for the valorization of the bergamot juice. Sep Sci Technol 48:537–46.

Catarino M, Mendes A. 2011. Dealcoholizing wine by membrane separation processes. Innov Food Sci Emerg Technol 12:330–7.

Cervantes-Elizarrarás A, Piloni-Martini J, Ramírez EM, Alanís-García E, GuemesVera N, Gómez-Aldapa CA, Zafra-Rojas QY, Cruz-Cansino NdS. 2017. Enzymatic inactivation and antioxidant properties of blackberry juice after thermoultrasound: optimization using response surface methodology. Ultrason Sonochem 34:371–9.

Chai C, Lee J, Lee Y, Na S, Park J. 2014. A combination of TiO_2-UV photocatalysis and high hydrostatic pressure to inactivate *Bacillus cereus* in freshly squeezed *Angelica keiskei* juice. LWT - Food Sci Technol 55:104–9.

Chaikham P, Apichartsrangkoon A, Jirarattanarangsri W, Van de Wiele T. 2012. Influence of encapsulated probiotics combined with pressurized longan juice on colon microflora and their metabolic activities on the exposure to simulated dynamic gastrointestinal tract. Food Res Int 49:133–42.

Chaikham P, Apichartsrangkoon A, Seesuriyachan P. 2014. Physical and biochemical qualities of pressurized and pasteurized longan juices upon storage. Emir J Food Agr 26:218–28.

Chaikham P, Apichartsrangkoon A. 2012. Comparison of dynamic viscoelastic and physicochemical properties of pressurized and pasteurized longan juices with xanthan addition. Food Chem 134:2194–200.

Chaikham P, Baipong S. 2016. Comparative effects of high hydrostatic pressure and thermal processing on physicochemical properties and bioactive components of Mao Luang (*Antidesma bunius* Linn.) juice. Chiang Mai J Sci 43:851–62.

Chaikham P, Chunthanom P, Apichartsrangkoon A. 2013. Storage stability of pennywort juice as affected by high pressure and thermal processing. Int Food Res J 20:3069–76.

Chaikham P, Prangthip P. 2015. Physical and biochemical properties of Yanang juice mixed with longan flower-honey following high pressure processing. Int Food Res J 22:1607–14.

Chaikham P. 2015. Comparison of high hydrostatic pressure and thermal processing on physicochemical and antioxidant properties of Maoberry (*Antidesma thwaitesianum* Müell. Arg.) juice. Int Food Res J 22:1993–2001.

Chakraborty S, Kaushik N, Rao PS, Mishra HN. 2014. High-pressure inactivation of enzymes: a review on its recent applications on fruit purees and juices. Compr Rev Food Sci Food Saf 13:578–96.

Chanukya BS, Rastogi NK. 2017. Ultrasound assisted forward osmosis concentration of fruit juice and natural colorant. Ultrason Sonochem 34:426–35.

Chen D, Pang X, Zhao J, Gao L, Liao X, Wu J, Li Q. 2015a. Comparing the effects of high hydrostatic pressure and high temperature short time on papaya beverage. Innov Food Sci Emerg Technol 32:16–28.

Chen D, Xi H, Guo X, Qin Z, Pang X, Hu X, Liao X, Wu J. 2013. Comparative study of quality of cloudy pomegranate juice treated by high hydrostatic pressure and high temperature short time. Innov Food Sci Emerg Technol 19:85–94.

Chen J, Tao XY, Sun AD, Wang Y, Liao XJ, Li LN, Zhang S. 2014. Influence of pulsed electric field and thermal treatments on the quality of blueberry juice. Int J Food Prop 17:1419–27.

Chen J, Zheng X, Dong J, Chen Y, Tian J. 2015b. Optimization of effective high hydrostatic pressure treatment of *Bacillus subtilis* in Hami melon juice. LWT - Food Sci Technol 60:1168–73.

Chen JL, Zhang J, Song L, Jiang Y, Wu J, Hu XS. 2010. Changes in microorganism, enzyme, aroma of hami melon (*Cucumis melo L.*) juice treated with dense phase carbon dioxide and stored at 4°C. Innov Food Sci Emerg Technol 11:623–9.

Chen X, Qin W, Ma L, Xu F, Jin P, Zheng Y. 2015c. Effect of high pressure processing and thermal treatment on physicochemical parameters, antioxidant activity and volatile compounds of green asparagus juice. LWT - Food Sci Technol 62:927–33.

Chen Y, Yu LJ, Rupasinghe HV. 2012. Effect of thermal and non-thermal pasteurisation on the microbial inactivation and phenolic degradation in fruit juice: a mini-review. J Sci Food Agric 93:981–6.

Chueca B, Ramírez N, Arvizu-Medrano SM, García-Gonzalo D, Pagán R. 2016. Inactivation of spoiling microorganisms in apple juice by a combination of essential oils' constituents and physical treatments. Food Sci Technol Int 22:389–98.

Cilla A, Lagarda MJ, Alegría A, de Ancos B, Cano MP, Sánchez Moreno C, Plaza L, Barberá R. 2011. Effect of processing and food matrix on calcium and phosphorous bioavailability from milk-based fruit beverages in Caco-2 cells. Food Res Int 44:3030–8.

Cissé M, Vaillant F, Bouquet S, Pallet D, Lutin F, Reynes M, Dornier M. 2011. A thermal concentration by osmotic evaporation of roselle extract, apple and grape juices and impact on quality. Innov Food Sci Emerg Technol 12:352–60.

Codina-Torrella I, Guamis B, Ferragut V, Trujillo AJ. 2017. Potential application of ultra-high pressure homogenization in the physico-chemical stabilization of tiger nuts' milk beverage. Innov Food Sci Emerg Technol 40:42–51.

Conidi C, Cassano A, Caiazzo F, Drioli E, 2017. Separation and purification of phenolic compounds from pomegranate juice by ultrafiltration and nanofiltration membranes. J Food Eng 195:1–13.

Conidi C, Cassano A, Drioliet E. 2011. A membrane-based study for the recovery of polyphenols from bergamot juice. J Membrane Sci 375: 182–90.

Corbo MR, Bevilacqua A, Petruzzi L, Casanova FP, Sinigaglia M. 2014. Functional beverages: the emerging side of functional foods: commercial trends, research, and health implications. Compr Rev Food Sci Food Saf 13:1192–206.

Corrales M, de Souza PM, Stahl MR, Fernández A. 2012. Effects of the decontamination of a fresh tiger nuts' milk beverage (horchata) with short wave ultraviolet treatments (UV-C) on quality attributes. Innov Food Sci Emerg Technol 13:163–8.

Costa MGM, Fonteles TV, De Jesus ALT, Rodrigues S. 2013. Sonicated pineapple juice as substrate for *L. casei* cultivation for probiotic beverage development: process optimisation and product stability. Food Chem 139:261–6.

Couto DS, Cabral LMC, da Matta VM, Deliza R, de Grandi Castro Freitas D. 2011a. Concentration of pineapple juice by reverse osmosis: physicochemical characteristics and consumer acceptance. Food Sci Technol 31:905–10.

Couto DS, Dornier M, Pallet D, Reynes M, Dijoux D, Freitas SP, Cabral LMC. 2011b. Evaluation of nanofiltration membranes for the retention of anthocyanins of açai (*Euterpe oleracea* Mart.) juice. Desalin Water Treat 27:108–13.

Cruz-Cansino NdS, Reyes-Hernández I, Delgado-Olivares L, Jaramillo-Bustos DP, Ariza-Ortega JA, Ramírez-Moreno ER. 2016. Effect of ultrasound on survival and growth of *Escherichia coli* in cactus pear juice during storage. Braz J Microbiol 47:431–7.

Cui Y, Lv W, Liu J, Wang B. 2012. Effect of different ending fermentation technologies on microbial-stability of Italian Riesling low alcohol sweet white wine. Adv Mat Res 393–395:1165–8.

Da Porto C, Decorti D, Tubaro F. 2010. Effects of continuous dense-phase CO_2 system on antioxidant capacity and volatile compounds of apple juice. Int J Food Sci Technol 45:1821–7.

Dadasaheb DW, Vasudish CR, Premavalli KS. 2015. Studies on effect of irradiation on functional properties of two ready-to-drink appetizer beverages and their shelf lives. Nutr Food Sci 45:388–99.

Daryaei H, Balasubramaniam VM. 2013. Kinetics of *Bacillus coagulans* spore inactivation in tomato juice by combined pressure-heat treatment. Food Control 30:168–75.

Das Purkayastha M, Kalita D, Das VK, Mahanta CL, Thakurb AJ, Chaudhuric MK. 2012. Effects of L-ascorbic acid addition on micro-filtered coconut water: Preliminary quality prediction study using ^{1}H-NMR, FTIR and GC-MS. Innov Food Sci Emerg Technol 13:184–99.

Dastgheib AM, Buntat Z, Sidik MAB. 2014. Chemical analysis on the effect of pulsed electric fields in pineapple juices preservation. Appl Mech Mater 554:588–92.

Delsart C, Grimi N, Boussetta N, Miot Sertier C, Ghidossi R, Vorobiev E, Mietton Peuchot M. 2015. Impact of pulsed electric field and high voltage electrical discharges on red wine microbial stabilization and quality characteristics. J Appl Microbiol 120:152–64.

Dershmukh SK, Sapkal VS, Sapkal RS. 2013. Dehydration of aloe vera juice by membrane distillation. J Chem Pharm Sci 6:66–72.

Dias DDRC, Barros ZMP, Carvalho CBOD, Honorato FA, Guerra NB, Azoubel PM. 2015. Effect of sonication on soursop juice quality. LWT - Food Sci Technol 62:883–9.

Dinçer C, Topuz A. 2015. Inactivation of *Escherichia coli* and quality changes in black mulberry juice under pulsed sonication and continuous thermosonication treatments. J Food Process Pres 39:1744–53.

Djas M, Bober M, Henczka M. 2011. New methods for inactivation of *Alicyclobacillus acidoterrestris* spores in apple juice concentrate. Chall Mod Technol 2:46–9.

Domingues RCC, Ramos, AA, Cardoso, VL, Reis MHM. 2014. Microfiltration of passion fruit juice using hollow fibre membranes and evaluation of fouling mechanisms. J Food Eng 121:73–9.

Donsì G, Ferrari G, Maresca P. 2010. Pasteurization of fruit juices by means of a pulsed high pressure process. J Food Sci 75:E169–77.

dos Santos Gomes F, da Costa PA, de Campos MBD, Couri S, Cabral LMC. 2011. Concentration of watermelon juice by reverse osmosis process. Desalin Water Treat 27:120–2.

Dubrović I, Herceg Z, Jambrak AR, Badanjak M, Dragović-Uzelac V. 2011. Effect of high intensity ultrasound and pasteurization on anthocyanin content in strawberry juice. Food Technol Biotechnol 49:196–204.

Echavarría AP, Falguera V, Torras C, Berdún C, Pagán J, Ibarz A. 2012. Ultrafiltration and reverse osmosis for clarification and concentration of fruit juices at pilot plant scale. LWT - Food Sci Technol 46:189–95.

Echavarría AP, Torras C, Pagán J, Ibarz A, 2011. Fruit juice processing and membrane technology application. Food Eng Rev 3:136–58.

Eissa HA, Shaheen MS, Botros HW. 2014. Impact of γ-Irradiation on aroma flavour, bio-active constituents and quality attributes of water melon juice. J Plant Pathol Microb 5:227.

Elez Garofulić I, Režek Jambrak A, Milošević S, Dragović-Uzelac V, Zorić Z, Herceg Z. 2015. The effect of gas phase plasma treatment on the anthocyanin and phenolic acid content of sour cherry Marasca (*Prunus cerasus* var. Marasca) juice. LWT - Food Sci Technol 62:894–900.

Engmann FN, Ma Y, Tchabo W, Ma H, Zhang H. 2014a. Optimization of ultrasonic and high hydrostatic pressure conditions on quality parameters of mulberry (*Morus moraceae*) juice using response surface methodology. J Food Quality 37:297–308.

Engmann FN, Ma Y, Zhang H, Yu L, Deng N. 2014b. The application of response surface methodology in studying the effect of heat and high hydrostatic pressure on anthocyanins, polyphenol oxidase, and peroxidase of mulberry (*Morus nigra*) juice. J Sci Food Agric 94:2345–56.

Engmann NF, Ma Y, Ying X, Qing Y. 2013. Investigating the effect of high hydrostatic pressure processing on anthocyanins composition of mulberry (*Morus moraceae*) juice.Czech J Food Sci 31:72–80.

Ennouri M, Ben Hassan I, Ben Hassen H, Lafforgue C, Schmitz P, Ayadi A. 2015. Clarification of purple carrot juice: analysis of the foulingmechanisms and evaluation of the juice quality. J Food Sci Technol 52: 2806–14.

Espina L, García-Gonzalo D, Laglaoui A, Mackey BM, Pagán R. 2013. Synergistic combinations of high hydrostatic pressure and essential oils or their constituents and their use in preservation of fruit juices. Int J Food Microbiol 161:23–30.

Evelyn, Kim HJ, Silva FVM. 2016. Modeling the inactivation of *Neosartorya fischeri* ascospores in apple juice by high pressure, power ultrasound and thermal processing. Food Control 59:530–7.

Evelyn, Silva FVM. 2016. High pressure processing pretreatment enhanced the thermosonication inactivation of *Alicyclobacillus acidoterrestris* spores in orange juice. Food Control 62:365–72.

Evrendilek GA, Avsar YK, Evrendilek F. 2016. Modelling stochastic variability and uncertainty in aroma active compounds of PEF-treated peach

nectar as a function of physical and sensory properties, and treatment time. Food Chem 190:634–42.

Evrendilek GA, Baysal T, Icier F, Yildiz H, Demirdoven A, Bozkurt H. 2012. Processing of fruits and fruit juices by novel electrotechnologies. Food Eng Rev 4:68–87.

Evrendilek GA. 2016. Change regime of aroma active compounds in response to pulsed electric field treatment time, sour cherry juice and apricot and peach nectars, and physical and sensory properties. Innov Food Sci Emerg Technol 33:195–205.

Falguera V, Garvín A, Garza S, Pagán J, Ibarz A. 2014. Effect of UV–Vis photochemical processing on pear juices from six different varieties. Food Bioprocess Technol 7:84–92.

Fan X. 2005. Formation of furan from carbohydrates and ascorbic acid following exposure to ionizing radiation and thermal processing. J Agric Food Chem 53:7826–31.

Farhadi Chitgar M, Aalami M, Maghsoudlou Y, Milani E. 2017. Comparative study on the effect of heat treatment and sonication on the quality of barberry (*Berberis vulgaris*) juice. J Food Process Pres 41: e12956.

Feng M, Ghafoor K, Seo B, Yang K, Park J. 2013. Effects of ultraviolet-C treatment in Teflon®-coil on microbial populations and physico-chemical characteristics of watermelon juice. Innov Food Sci Emerg Technol 19:133–9.

Ferrario M, Alzamora SM, Guerrero S. 2013. Inactivation kinetics of some microorganisms in apple, melon, orange and strawberry juices by high intensity light pulses. J Food Eng 118:302–11.

Ferrario M, Alzamora SM, Guerrero S. 2015. Study of the inactivation of spoilage microorganisms in apple juice by pulsed light and ultrasound. Food Microbiol 46:635–42.

Ferrario M, Guerrero S, Alzamora SM. 2014. Study of pulsed light-induced damage on *Saccharomyces cerevisiae* in apple juice by flow cytometry and transmission electron microscopy. Food Bioprocess Technol 7:1001–11.

Feyaerts J, Rogiers G, Corthouts J, Michiels CW. 2015. Thiol-reactive natural antimicrobials and high pressure treatment synergistically enhance bacterial inactivation. Innov Food Sci Emerg Technol 27:26–34.

Firmán LR, Pagliero CP, Ochoa NA, Marchese J. 2014. PVDF/PMMA membranes for lemon juice clarification: fouling analysis. Desalin Water Treat 55:1167–76.

Flores-Cervantes DX, Palou E, López-Malo A. 2013. Efficacy of individual and combined UVC light and food antimicrobial treatments to inactivate *Aspergillus flavus* or *A. niger* spores in peach nectar. Innov Food Sci Emerg Technol 20:244–52.

Fonteles TV, Costa MGM, de Jesus ALT, de Miranda MRA, Fernandes FAN, Rodrigues S. 2012. Power ultrasound processing of cantaloupe melon juice: effects on quality parameters. Food Res Int 48:41–8.

Frandsen HB, Markedal KE, Martín-Belloso O, Sánchez-Vega R, Soliva-Fortuny R, Sørensen H, Sørensen S, Sørensen JC. 2014. Effects of novel processing techniques on glucosinolates and membrane associated myrosinases in broccoli. Pol J Food Nutr Sci 64:17–25.

Fredericks IN, du Toit M, Krügel M. 2011. Efficacy of ultraviolet radiation as an alternative technology to inactivate microorganisms in grape juices and wines. Food Microbiol 28:510–7.

Gabriel AA, Aba RPM, Tayamora DJL, Colambo JCR, Siringan MAT, Rosario LMD, Tumlos RB, Ramos HJ. 2016. Reference organism selection for microwave atmospheric pressure plasma jet treatment of young coconut liquid endosperm. Food Control 69:74–82.

Gabriel AA, Aguila MLC, Tupe KAMT. 2015. Application of ultraviolet-C radiation to inactivate acid-and-desiccation stressed *Salmonella enterica* in young and mature coconut liquid endosperm mix beverage. Food Control 51:425–32.

Gabriel AA. 2015. Combinations of selected physical and chemical hurdles to inactivate *Escherichia coli* O157:H7 in apple and orange juices. Food Control 50:722–8.

Gao G, Zhao L, Ma Y, Wang Y, Sun Z, Liao X. 2015. Microorganisms and some quality of red grapefruit juice affected by high pressure processing and high temperature short time. Food Bioprocess Technol 8:2096–108.

Gao J, Rupasinghe HPV. 2012. Nutritional, physicochemical and microbial quality of ultrasound-treated apple-carrot juice blends. Food Nutr Sci 3:212–8.

Garcia Loredo AB, Guerrero SN, Alzamora SM. 2015. Inactivation kinetics and growth dynamics during cold storage of *Escherichia coli* ATCC 11229, *Listeria innocua* ATCC 33090 and *Saccharomyces cerevisiae* KE162 in peach juice using aqueous ozone. Innov Food Sci Emerg Technol 29:271–9.

García-García R, Escobedo-Avellaneda Z, Tejada-Ortigoza V, Martín-Belloso O, Valdez-Fragoso A, Welti-Chanes J. 2015. Hurdle technology applied to prickly pear beverages for inhibiting *Saccharomyces cerevisiae* and *Escherichia coli*. Lett Appl Microbiol 60:558–64.

Garino C, Zitelli F, Travaglia F, Colsson JD, Cravotto G, Arlorio M. 2012. Evaluation of the impact of sequential microwave/ultrasound processing on the IgE binding properties of Pru p 3 in treated peach juice. J Agric Food Chem 60:8755–62.

Garud SR, Priyanka BS, Negi PS, Rastogi NK. 2017. Effect of thermosonication on bacterial count in artificially inoculated model system and natural microflora of sugarcane juice. J Food Process Pres 41:e12813.

Gayán E, Serrano MJ, Monfort S, Álvarez I, Condón S. 2012. Combining ultraviolet light and mild temperatures for the inactivation of *Escherichia coli* in orange juice. J Food Eng 113:598–605.

Gayán E, Serrano MJ, Monfort S, Álvarez I, Condón S. 2013. Pasteurization of apple juice contaminated with *Escherichia coli* by a combined UV–mild temperature treatment. Food Bioprocess Technol 6:3006–16.

Gialleli AI, Bekatorou A, Kanellaki M, Nigam P, Koutinas AA. 2016. Apple juice preservation through microbial adsorption by nano/micro-tubular cellulose. Innov Food Sci Emerg Technol 33:416–21.

Gironés-Vilaplana A, Huertas J-P, Moreno DA, Periago PM, García-Viguera C. 2016. Quality and microbial safety evaluation of new isotonic beverages upon thermal treatments. Food Chem 194:455–62.

Gomes FS, Costa PA, Campos MBD, Tonon RV, Couri S, Cabral LMC. 2013. Watermelon juice pretreatment with microfiltration process for obtaining lycopene. Int J Food Sci Technol 48:601–8.

Gomes WF, Tiwari BK, Rodriguez O, de Brito ES, Fernandes FAN, Rodrigues S. 2017. Effect of ultrasound followed by high pressure processing on prebiotic cranberry juice. Food Chem 218:261–8.

Gómez-Díaz JJ, Santiesteban-López A, Palou E, López-Malo A. 2011. *Zygosaccharomyces bailii* inactivation by means of UV light and low-frequency ultrasound treatments. J Food Protect 10:1751–5.

Gómez-López VM, Orsolani L, Martínez-Yépez A, Tapia MS. 2010. Microbiological and sensory quality of sonicated calcium-added orange juice. LWT - Food Sci Technol 43:808–13.

Gong Y, Yu JY, Qian P, Meng J, Zhang XJ, Lu RR. 2015. Comparative study of the microbial stability and quality of carrot juice treated by high-pressure processing combined with mild temperature and conventional heat treatment. J Food Process Eng 38:395–404.

González-Arenzana L, Portu J, López R, López N, Santamaría P, Garde-Cerdán T, López-Alfaro I. 2015. Inactivation of wine-associated microbiota by continuous pulsed electric field treatments. Innov Food Sci Emerg Technol 29:187–92.

Gouma M, Álvarez I, Condón S, Gayán E. 2015a. Modelling microbial inactivation kinetics of combined UV-H treatments in apple juice. Innov Food Science Emerg Technol 27:111–20.

Gouma M, Gayán E, Raso J, Condón S, Álvarez I. 2015b. Influence of dimethyl dicarbonate on the resistance of *Escherichia coli* to a combined UV-Heat treatment in apple juice. Front Microbiol 6:501.

Groenewald WH, Gouws PA, Cilliers FP, Witthuhn RC. 2013. The use of ultraviolet radiation as a non-thermal treatment for the inactivation of *Alicyclobacillus acidoterrestris* spores in water, wash water from a fruit processing plant and grape juice concentrate. J New Generat Sci 11:19–32.

Guan Y, Zhou L, Bi J, Yi J, Liu X, Chen Q, Wu X, Zhou M. 2016. Change of microbial and quality attributes of mango juice treated by high pressure homogenization combined with moderate inlet temperatures during storage. Innov Food Sci Emerg Technol 36:320–9.

Guerrero-Beltrán J, Barbosa-Cánovas GV, Welti-Chanes J. 2011. High hydrostatic pressure effect on *Saccharomyces cerevisiae*, *Escherichia coli* and *Listeria innocua* in pear nectar. J Food Quality 34:371–8.

Guevara M, Tapia MS, Gómez-López VM. 2012. Microbial inactivation and quality of guava and passion fruit nectars treated by UV-C light. Food Bioprocess Technol 5:803–7.

Gunathilake KDPP, Yu LJ, Rupasinghe HPV. 2014. Reverse osmosis as a potential technique to improve antioxidant properties of fruit juices used for functional beverages. Food Chem 148:335–41.

Guo M, Jin TZ, Geveke DJ, Fan X, Sites JE, Wang L. 2014. Evaluation of microbial stability, bioactive compounds, physicochemical properties, and consumer acceptance of pomegranate juice processed in a commercial scale pulsed electric field system. Food Bioprocess Technol 7:2112–20.

Guo M, Wu J, Xu Y, Xiao G, Zhang M, Chen Y. 2011. Effects on microbial inactivation and quality attributes in frozen lychee juice treated by supercritical carbon dioxide. Eur Food Res Technol 232:803–11.

Gupta R, Balasubramaniam VM, Schwartz SJ, Francis DM. 2010. Storage stability of lycopene in tomato subjected to combined pressure-heat treatments. J Agric Food Chem 58:8305–13.

Gurak PD, Cabral LMC, Rocha-Leão MHM, Matta VM, Freitas SP. 2010. Quality evaluation of grape juice concentrated by reverse osmosis. J Food Eng 96:421–6.

Gurtler JB, Bailey RB, Geveke DJ, Zhang HQ. 2011. Pulsed electric field inactivation of *E. coli* O157:H7 and non-pathogenic surrogate *E. coli* in strawberry juice as influenced by sodium benzoate, potassium sorbate, and citric acid. Food Control 22:1689–94.

Guzel BH, Arroyo C, Condón S, Pagán R, Bayindirli A, Alpas H. 2014. Inactivation of *Listeria monocytogenes* and *Escherichia coli* by ultrasonic waves under pressure at nonlethal (manosonication) and lethal temperatures (manothermosonication) in acidic fruit juices. Food Bioprocess Technol 7:1701–12.

Hakguder Taze B, Unluturk S, Buzrul S, Alpas H. 2015. The impact of UV-C irradiation on spoilage microorganisms and colour of orange juice. J Food Sci Technol 52:1000–7.

Halim H, Noranizan M, Sobhi B, Sew CC, Karim R, Osman A. 2012. Non thermal pasteurization of Pitaya (*Hylocereus polyrhizus*) juice using the hurdle concept. Int Food Res J 19:1457–61.

Hao H, Zhou T, Koutchma T, Wu F, Warriner K. 2016. High hydrostatic pressure assisted degradation of patulin in fruit and vegetable juice blends. Food Control 62:237–42.

Hartyáni P, Dalmadi I, Cserhalmi Z, Kántor DB, Tóth-Markus M, Sass-Kiss A. 2011. Physical–chemical and sensory properties of pulsed electric field and high hydrostatic pressure treated citrus juices. Innov Food Sci Emerg Technol 12:255–60.

Hartyáni P, Dalmadi I, Knorr D. 2013. Electronic nose investigation of *Alicyclobacillus acidoterrestris* inoculated apple and orange juice treated by high hydrostatic pressure. Food Control 32:262–9.

He Z, Tao Y, Zeng M, Zhang S, Tao G, Qin F, Chen J. 2016. High pressure homogenization processing, thermal treatment and milk matrix affect *in vitro* bioaccessibility of phenolics in apple, grape and orange juice to different extents. Food Chem 200:107–16.

Hernández-Carranza P, Ruiz-López II, Pacheco-Aguirre FM, Guerrero-Beltrán JÁ, Ávila-Sosa R, Ochoa-Velasco CE. 2016. Ultraviolet-C light effect on physicochemical, bioactive, microbiological, and sensorial characteristics of carrot (*Daucus carota*) beverages. Food Sci Technol Int 22:536–46.

Hiremath ND, Ramaswamy HS. 2012. High-pressure destruction kinetics of spoilage and pathogenic microorganisms in mango juice. J Food Process Pres 36:113–25.

Hojjatpanah G, Emam-Djomeh Z, Ashtari AK, Mirsaeedghazi H, Omid M. 2011. Evaluation of the fouling phenomenon in the membrane clarification of black mulberry juice. Int J Food Sci Technol 46:1538–44.

Hong S, Mendonc AF, Daraba A, Shaw A. 2014. Radiation resistance and injury in starved *Escherichia coli* O157:H7 treated with electron-beam irradiation in 0.85% saline and in apple juice. Foodborne Pathog Dis 11:900–6.

Huang HW, Chang YH, Wang CY. 2015. High pressure pasteurization of sugarcane juice: evaluation of microbiological shelf life and quality evolution during refrigerated storage. Food Bioprocess Technol 8:2483–94.

Huang K, Jiang T, Wang W, Gai L, Wang J. 2014. A comparison of pulsed electric field resistance for three microorganisms with different biological factors in grape juice via numerical simulation. Food Bioprocess Technol 7:1981–95.

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.

Hurtado A, Guàrdia MD, Picouet P, Jofré A, Ros JM, Bañón S. 2017. Stabilization of red fruit-based smoothies by high pressure processing. Part A. Effects on microbial growth, enzyme activity, antioxidant capacity and physical stability. J Sci Food Agric 97:770–6.

Hurtado A, Picouet P, Jofré A, Guàrdia MD, Ros JM, Bañón S. 2015. Application of high pressure processing for obtaining "fresh-like" fruit smoothies. Food Bioprocess Technol 8:2470–82.

Hwang HJ, Cheigh CI, Chung MS. 2015. Relationship between optical properties of beverages and microbial inactivation by intense pulsed light. Innov Food Sci Emerg Technol 31:91–6.

Iftikhar T, Wagner ME, Rizvi SSH. 2014. Enhanced inactivation of pectin methyl esterase in orange juice using modified supercritical carbon dioxide treatment. Int J Food Sci Technol 49:804–10.

Janiszewska E, Sakowski P. 2013. Effect of the ultrasound on the carrot juices freezing process. Agric Eng 4:49–57.

Jayachandran LE, Chakraborty S, Rao PS. 2015. Effect of high pressure processing on physicochemical properties and bioactive compounds in litchi based mixed fruit beverage. Innov Food Sci Emerg Technol 28:1–9.

Jayanti VK, Rai P, Dasgupta S, De S. 2010. Quantification of flux decline and design of ultrafiltration system for clarification of tender coconut water. J Food Process Eng 33:128–43.

Jayathunge KGLR, Grant IR, Linton M, Patterson MF, Koidis A. 2015. Impact of long-term storage at ambient temperatures on the total quality and stability of high-pressure processed tomato juice. Inn Food Sci Emerg Technol 32:1–8.

Jayathunge KGLR, Stratakos AC, Cregenzán-Albertia O, Grant IR, Lyng J, Koidis A. 2017. Enhancing the lycopene in vitro bioaccessibility of tomato juice synergistically applying thermal and non-thermal processing technologies. Food Chem 221:698–0705.

Jiang B, Mantri N, Hu Y, Lu J, Jiang W, Lu H. 2015. Evaluation of bioactive compounds of black mulberry juice after thermal, microwave, ultrasonic processing, and storage at different temperatures. Food Sci Technol Int 21:392–9.

Jiménez-Aguilar DM, Escobedo-Avellaneda Z, Martín-Belloso O, Gutiérrez-Uribe J, Valdez-Fragoso A, García-García R, Torres JA, Welti-Chanes J. 2015. Effect of high hydrostatic pressure on the content of phytochemical compounds and antioxidant activity of prickly pears (*Opuntia ficus-indica*) beverages. Food Eng Rev 7:198–208.

Jiménez-Sánchez C, Lozano-Sánchez J, Segura-Carretero A, Fernández-Gutiérrez A. 2017a. Review: alternatives to conventional thermal treatments in fruit-juice processing. part 1: techniques and applications. critical reviews in food science and nutrition. Crit Rev Food Sci Nutr 57:501–23.

Jiménez-Sánchez C, Lozano-Sánchez J, Segura-Carretero A, Fernández-Gutiérrez A. 2017b. Alternatives to conventional thermal treatments in fruit-juice processing. part 2: effect on composition, phytochemical content, and physicochemical, rheological, and organoleptic properties of fruit juices. critical reviews in food science and nutrition. Crit Rev Food Sci Nutr 57:637–52.

Jin TZ, Guo M, Yang R. 2014. Combination of pulsed electric field processing and antimicrobial bottle for extending microbiological shelf-life of pomegranate juice. Inn Food Sci Emerg Technol 26:153–8.

Jo C, Ahn DU, Lee KH. 2012. Effect of gamma irradiation on microbiological, chemical, and sensory properties of fresh ashitaba and kale juices. Radiat Phys Chem 81:1076–8.

Jo C, Lee KH. 2012. Comparison of the efficacy of gamma and UV irradiation in sanitization of fresh carrot juice. Radiat Phys Chem 81:1079–81.

Juarez-Enriquez E, Salmeron-Ochoa I, Gutierrez-Mendez N, Ramaswamy HS, Ortega-Rivas E. 2015. Shelf life studies on apple juice pasteurised by ultrahigh hydrostatic pressure. LWT - Food Sci Technol 62:915–9.

Kahraman O, Lee H, Zhang W, Feng H. 2017. Manothermosonication (MTS) treatment of apple-carrot juice blend for inactivation of *Escherichia coli* O157:H7. Ultrason Sonochem 38:820–8.

Karacam CH, Sahin S, Oztop MH. 2015. Effect of high pressure homogenization (microfluidization) on the quality of Ottoman Strawberry (*F. Ananassa*) juice. LWT - Food Sci Technol 64:932–7.

Kathiravan T, Kumar R, Lakshmana JH, Kumaraswamy MR, Nadanasabapathi S. 2014. Pulsed electric field processing of functional drink based on tender coconut water (*Cococus nucifera* L.) - nannari (*Hemidesmus indicus*) blended beverage. Croat J Food Sci Technol 6:84–96.

Kathiravan T, Nadanasabapathi S, Kumar R. 2013. Optimization of pulsed electric field processing conditions for passion fruit juice (*Passiflora edulis*) using Response Surface Methodology. Int J Adv Res 1:399–411.

Katiyo W, Yang R, Zhao W, Hua X, Gasmalla MAA. 2014. Optimization of combined pulsed electric fields and mild temperature processing conditions for red apple juice polyphenol oxidase and peroxidase inactivation. Adv J Food Sci Technol 6:638–46.

Kaushik N, Gondi AR, Rana R, Srinivasa Rao P. 2015. Application of fuzzy logic technique for sensory evaluation of high pressure processed mango pulp and litchi juice and its comparison to thermal treatment. Innov Food Sci Emerg Technol 32:70–8.

Kaushik N, Kaur BP, Rao PS. 2014. Application of high pressure processing for shelf life extension of litchi fruits (*Litchi chinensis* cv. Bombai) during refrigerated storage. Food Sci Technol Int 20:527–41.

Kaushik N, Kaur BP, Rao PS. 2016. Inactivation of polyphenol oxidase and peroxidase enzymes during pulsed, static and cyclic pressurization of litchi (*Litchi chinensis*) juice. Food Bioprod Process 100:412–23.

Kaya Z, Yildiz S, Ünlütürk, S. 2015. Effect of UV-C irradiation and heat treatment on the shelf life stability of a lemon - melon juice blend: multivariate statistical approach. Innov Food Sci Emerg Technol 29:230–9.

Kayalvizhi V, Pushpa AJS, Sangeetha G, Antony U. 2016. Effect of pulsed electric field (PEF) treatment on sugarcane juice. J Food Sci Technol 53:1371–9.

Keenan DF, Rößle C, Gormley R, Butler F, Brunton NP. 2012a. Effect of high hydrostatic pressure and thermal processing on the nutritional quality and enzyme activity of fruit smoothies. LWT – Food Sci Technol 45:50–7.

Keenan DF, Tiwari BK, Patras A, Gormley R, Butler F, Brunton NP. 2012b. Effect of sonication on the bioactive, quality and rheological characteristics of fruit smoothies. Int J Food Sci Technol 47:827–36.

Khandpur P, Gogate PR. 2015. Effect of novel ultrasound based processing on the nutrition quality of different fruit and vegetable juices. Ultrason Sonochem 27:125–36.

Khandpur P, Gogate PR. 2016. Evaluation of ultrasound based sterilization approaches in terms of shelf life and quality parameters of fruit and vegetable juices. Ultrason Sonochem 29:337–53.

Kiang WS, Bhat R, Rosma A, Cheng LH. 2013. Effects of thermosonication on the fate of *Escherichia coli* O157:H7 and *Salmonella Enteritidis* in mango juice. Lett Appl Microbiol 56:251–7.

Kondapalli N, Sadineni V, Variyar PS, Sharma A, Obulama VSR. 2014. Impact of γ-irradiation on antioxidant capacity of mango (*Mangifera indica* L.) wine from eight Indian cultivars and the protection of mango wine against DNA damage caused by irradiation. Process Biochem 49: 1819–30.

Kongkachuichai R, Charoensiri R, Yakoh K, Kringkasemsee A, Insung P. 2015. Nutrients value and antioxidant content of indigenous vegetables from Southern Thailand. Food Chem 173:836–46.

Koshani R, Ziaee E, Niakousari M, Golmakani MT. 2014. Optimization of thermal and thermosonication treatments on pectin methyl esterase inactivation of sour orange juice (*Citrus aurantium*). J Food Process Pres 39:567–73.

Koutchma T, Popović V, Ros-Polski V, Popielarz A. 2016. Effects of ultraviolet light and high-pressure processing on quality and health-related constituents of fresh juice products. Comp Rev Food Sci Food Saf 15:844–67.

Kubo MTK, Augusto PED, Cristianini M. 2013. Effect of high pressure homogenization (HPH) on the physical stability of tomato juice. Food Res Int 51:170–9.

Kujawa J, Guillen-Burrieza E, Arafat HA, Kurzawa M, Wolan A, Kujawski W. 2015. Raw juice concentration by osmotic membrane distillation process with hydrophobic polymeric membranes. Food Bioprocess Technol 8:2146–58.

Kujawski W, Sobolewska A, Jarzynka K, Güell C, Ferrando M, Warczok J. 2013. Application of osmotic membrane distillation process in red grape juice concentration. J Food Eng 116:801–8.

Kumar R, Bawa AS, Kathiravan T, Nadanasabapathi S. 2015. Optimization of pulsed electric field parameters for mango nectar processing using response surface methodology. Int Food Res J 22:1353–60.

Kwon SC, Choi GH, Yu KW, Lee KH. 2010. Microbiological and physicochemical changes of vegetable juices (*Angelica keiskei* and *Brassica loeracea* var. *acephala*) treated by UV irradiation. J Korean Soc Food Sci Nutr 39:1030–7.

La Cava ELM, Sgroppo SC. 2015. Evolution during refrigerated storage of bioactive compounds and quality characteristics of grapefruit [*Citrus paradisi* (Macf.)] juice treated with UV-C light. LWT - Food Sci Technol 63:1325–33.

Laorko A, Tongchitpakdee S, Youravong W. 2013. Storage quality of pineapple juice non-thermally pasteurized and clarified by microfiltration. J Food Eng 116:554–61.

Lee H, Kim H, Cadwallader KR, Feng H, Martin SE. 2013a. Sonication in combination with heat and low pressure as an alternative pasteurization treatment - Effect on *Escherichia coli* K12 inactivation and quality of apple cider. Ultrason Sonochem 20:1131–8.

Lee SH, Yamada K, Jun S. 2013b. Ultraviolet radiation assisted with ohmic current for microbial inactivation in apple juice. T ASABE 56:1085–91.

Lee SY, Park SH, Kang DH 2014. Inactivation of *Alicyclobacillus acidoterrestris* spores in apple and orange juice concentrates by gamma irradiation. J Food Protect 77:339–44.

Leite TS, Augusto PED, Cristianini M. 2014. The use of high pressure homogenization (HPH) to reduce consistency of concentrated orange juice (COJ). Innov Food Sci Emerg Technol 26:124–33.

Leite TS, Augusto PED, Cristianini M. 2015. Using high pressure homogenization (HPH) to change the physical properties of cashew apple juice. Food Biophys 10:169–80.

Li X, Farid M. 2016. A review on recent development in non-conventional food sterilization technologies. J Food Eng 182: 33–45.

Li R, Wang Y, Wang S, Liao X. 2015. Comparative study of changes in microbiological quality and physicochemical properties of N_2-induced and N_2-degassed banana smoothies after high pressure processing. Food Bioprocess Technol 8:333–42.

Li W, Pan J, Xie H, Yang Y, Zhou D, Zhu Z. 2012. Pasteurization of fruit juices of different ph values by combined high hydrostatic pressure and carbon dioxide. J Food Protect 75:1873–7.

Liang J, Xu J, Pan J, Ge M, Zong K. 2015. Identification of the main allergenic proteins in high hydrostatic pressure pineapple juice and assessing the influence of pressure on their allergenicity. Int J Food Prop 18:2134–44.

Liao H, Zhang L, Hu X, Liao X. 2010b. Effect of high pressure CO_2 and mild heat processing on natural microorganisms in apple juice. Int J Food Microbiol 137:81–7.

Liao HM, Kong XZ, Zhang ZY, Liao XJ, Hu XS. 2010a. Modeling the inactivation of *Salmonella typhimurium* by dense phase carbon dioxide in carrot juice. Food Microbiol 27:94–100.

Liu F, Li R, Wang Y, Bi, X, Liao X. 2014. Effects of high hydrostatic pressure and high-temperature short-time on mango nectars: changes in microorganisms, acid invertase, 5-hydroxymethylfurfural, sugars, viscosity, and cloud. Innov Food Sci Emerg Technol 22:22–30.

Liu F, Zhang X, Zhao L, Wang Y, Liao X. 2016. Potential of high-pressure processing and high-temperature/short-time thermal processing on microbial, physicochemical and sensory assurance of clear cucumber juice. Innov Food Sci Emerg Technol 34:51–8.

Liu Q, Wang R-F, Zhang B-B, Zhao X-Y, Wang D, Zhang C. 2015. Protein secondary structure changes of watermelon juice treated with high hydrostatic pressure by FTIR spectroscopy. J Food Process Eng 37: 543–9.

Liu RH. 2013. Dietary bioactive compounds and their health implications. J Food Sci 78(Suppl 1):A18–25.

Liu Y, Hu XS, Zhao XY, Zhang C. 2013. Inactivation of polyphenol oxidase from watermelon juice by high pressure carbon dioxide treatment. J Food Sci Technol 50:317–24.

Loginov M, Loginova K, Lebovka N, Vorobiev E. 2011. Comparison of dead-end ultrafiltration behaviour and filtrate quality of sugar beet juices obtained by conventional and "cold" PEF-assisted diffusion. J Membrane Sci 377:273–83.

Lukas AR. 2013. Use of high pressure processing to reduce foodborne pathogens in coconut water. PhD Thesis. Virginia Polytechnic Institute and State University, Blacksbug, Virginia.

Lung HM, Cheng YC, Chang YH, Huang HW, Yang BB, Wang CY. 2015. Microbial decontamination of food by electron beam irradiation. Trends Food Sci Technol 44:66–78.

Ma TJ, Lan WS. 2015. Effects of non-thermal plasma sterilization on volatile components of tomato juice. Int J Environ Sci Technol 12:3767–72.

Ma Y, Hu X, Chen J, Zhao G, Liao X, Chen F, Wu J, Wang Z. 2010. Effect of UHP on enzyme, microorganism and flavor in cantaloupe (*Cucumis melo* L.) juice. J Food Process Eng 33:540–53.

Maftei NA, Ramos-Villarroel AY, Nicolau AI, Martín-Belloso O, Soliva-Fortuny R. 2015. Influence of processing parameters on the pulsed-light inactivation of *Penicillium expansum* in apple juice. Food Control 41:27–31.

Manns DC, Churey JJ, Worobo RW. 2015. Variable efficacy of the proteinaceous antifungal YvgO in select fruit juices and teas as a complement with UV methods of food protection. J Food Protect 78:1851–60.

Maresca P, Donsì F, Ferrari G. 2011. Application of a multi-pass high-pressure homogenization treatment for the pasteurization of fruit juices. J Food Eng 104:364–72.

Marsh AJ, Hill C, Ross RP, Cotter PD. 2014. Fermented beverages with health-promoting potential: Past and future perspectives. Trends Food Sci Technol 38:113–24.

Marszałek K, Krzyżanowska J, Woźniak L, Skąpska S. 2016. Kinetic modelling of tissue enzymes inactivation and degradation of pigments and polyphenols in cloudy carrot and celery juices under supercritical carbon dioxide. J Supercrit Fluid 117:26–32.

Marszałek K, Krzyżanowska J, Woźniak L, Skąpska S. 2017a. Kinetic modelling of polyphenol oxidase, peroxidase, pectin esterase, polygalacturonase, degradation of the main pigments and polyphenols in beetroot juice during high pressure carbon dioxide treatment. LWT - Food Sci Technol. 85:412–7.

Marszałek K, Mitek M, Skąpska S. 2011. Application of high hydrostatic pressures (HHP) to stabilize strawberry juices and nectars. Zywn-Nauk Technol JA 1:112–23.

Marszałek K, Skąpska S, Woźniak L, Sokołowska B. 2015a. Application of supercritical carbon dioxide for the preservation of strawberry juice: microbial and physicochemical quality, enzymatic activity and the degradation kinetics of anthocyanins during storage. Innov Food Sci Emerg Technol 32:101–9.

Marszałek K, Woźniak L, Skąpska S. 2015b. Effect of supercritical carbon dioxide on selected quality parameters of preserved strawberry juice. Zywn-Nauk Technol JA 2:114–23.

Marszałek K., Kruszewski B., Woźniak L, Skąpska S. 2017b. The application of supercritical carbon dioxide for the stabilization of native and commercial polyphenol oxidases and peroxidases in cloudy apple juice (cv. *Golden Delicious*). Innov Food Sci Emerg Technol 39:42–8.

Martín-Belloso O, Sobrino-López A. 2011. Combination of pulsed electric fields with other preservation techniques. Food Bioprocess Technol 4:954–68.

Martínez-Flores HE, Garnica-Romo MG, Bermúdez-Aguirre D, Pokhrel PR, Barbosa-Cánovas GV. 2015. Physico-chemical parameters, bioactive compounds and microbial quality of thermo-sonicated carrot juice during storage. Food Chem 172:650–6.

McKay AM, Linton M, Stirling J, Mackle A, Patterson MF. 2011. A comparative study of changes in the microbiota of apple juice treated by high hydrostatic pressure (HHP) or high pressure homogenisation (HPH). Food Microbiol 28:1426–31.

McNamee C, Noci F, Cronin DA, Lyng JG, Morgan DJ, Scannell AGM. 2010. PEF based hurdle strategy to control *Pichia fermentans*, *Listeria innocua* and *Escherichia coli* k12 in orange juice. Int J Food Microbiol 138:13–8.

Meneses N, Jaeger H, Knorr D. 2011. Minimization of thermal impact by application of electrode cooling in a co-linear PEF treatment chamber. J Food Sci 76: E536–43.

Mert M, Buzrul S, Alpas H. 2013. Effects of high hydrostatic pressure on microflora and some quality attributes of grape juice. High Pressure Res 33:55–63.

Milani PG, Prato AM, Monteiro ARG, Maioral MF, Marchi LB, Da Costa SC. 2015. Assessment of operating parameters, membrane fouling and juice quality during acerola ultrafiltration. Chem Engineer Trans 44:325–30.

Mirsaeedghazi H, Emam-Djomeh Z. 2017. Clarification of bitter orange (*Citrus aurantium*) juice using microfiltration with mixed cellulose esters membrane. J Food Process Pres 41:e12738.

Mishra BB, Gautam S, Sharma A. 2011. Shelf life extension of sugarcane juice using preservatives and gamma radiation processing. J Food Sci 76:M573–8.

Mohd-Hanif H, Shamsudin R, Adzahan NM. 2016. UVC dosage effects on the physico-chemical properties of lime (*Citrus aurantifolia*) juice. Food Sci Biotechnol 25:63–7.

Mohideen FW, Solval KM, Li J, Zhang J, Chouljenko A, Chotiko A, Prudente AD, Bankston JD, Sathivel S. 2015. Effect of continuous ultra-sonication on microbial counts and physico-chemical properties of blueberry (*Vaccinium corymbosum*) juice. LWT - Food Sci Technol 60:563–70.

Mondal S, Biswas PP, De S. 2016. Clarification and storage study of bottle gourd (*Lagenaria siceraria*) juice by hollow fiber ultrafiltration. Food Bioprod Process 100:1–15.

Mondal S, Cassano A, De S. 2014. Modeling of cake layer controlled fruit juice microfiltration in a radial cross flow cell. Food Bioprocess Technol 7:355–70.

Moody A, Marx G, Swanson BG, Bermúdez-Aguirre D. 2014. A comprehensive study on the inactivation of *Escherichia coli* under non thermal technologies: High hydrostatic pressure, pulsed electric fields and ultrasound. Food Control 37:305–14.

Morales-de la Peña M, Salvia-Trujillo L, Rojas-Graü MA, Martín-Belloso O. 2010. 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 43:872–81.

Morata A, Benito S, González MC, Palomero F, Tesfaye W, Suárez-Lepe JA. 2012. Cold pasteurisation of red wines with high hydrostatic pressure to control *Dekkera/Brettanomyces*: effect on both aromatic and chromatic quality of wine. Eur Food Res Technol 235:147–54.

Moreira RM, Martins ML, Leite Júnior BRdeC, Martins EMF, Ramos AM, Cristianini M, Campos ANdaR, Stringheta PC, Silva VRO, Canuto JW, de Oliveira DC, Pereira DCdeS. 2017. Development of a juçara and Ubá mango juice mixture with added *Lactobacillus rhamnosus* GG processed by high pressure. LWT - Food Sci Technol 77:259–68.

Mosqueda-Melgar J, Raybaudi-Massilia R, Martín-Belloso O. 2012. Microbiological shelf life and sensory evaluation of fruit juices treated by high-intensity pulsed electric fields and antimicrobials. Food Bioprod Process 90:205–14.

Moussa-Ayoub TE, Jaeger H, Knorr D, El-Samahy S, Kroh LW, Rohn S. 2017. Impact of pulsed electric fields, high hydrostatic pressure, and thermal pasteurization on selected characteristics of *Opuntia dillenii* cactus juice. LWT - Food Sci Technol 79:534–42.

Moussa-Ayoub TE, Jaeger H, Knorr D, El-Samahy S, Rohn S, Kroh LW. 2011. Impact of traditional and innovative technologies on some characteristics and bioactive compounds of *Opuntia macrorhiza* juice. Procedia Food Sci 1:1410–6.

Mtaoua H, Sánchez-Vega R, Ferchichi A, Martín-Belloso O. 2017. Impact of high-intensity pulsed electric fields or thermal treatment on the quality attributes of date juice through storage. J Food Process Pres 4:e13052.

Müller A, Briviba K, Gräf R, Herrmann C, Kuballa T, Stahl MR. 2013. UV-C treatment using Dean vortex technology – impact on apple juice enzymes and toxicological potential. Innov Food Sci Emerg Technol 20:238–43.

Müller A, Noack L, Greiner R, Stahl MR, Posten C. 2014. Effect of UV-C and UV-B treatment on polyphenol oxidase activity and shelf life of apple and grape juices. Innov Food Sci Emerg Technol 26:498–504.

Muñoz A, Caminiti IM, Palgan I, Pataro G, Noci F, Morgan DJ, Cronin DA, Whyte P, Ferrari G, Lyng JG. 2012. Effects on *Escherichia coli* inactivation and quality attributes in apple juice treated by combinations of pulsed light and thermosonication. Food Res Int 45:299–305.

Muñoz A, Palgan I, Noci F, Morgan DJ, Cronin DA, Whyte P, Lyng JG. 2011. Combinations of high intensity light pulses and thermosonication for the inactivation of *Escherichia coli* in orange juice. Food Microbiol 28:1200–4.

Mytton OT, Nnoaham K, Eyles H, Scarborough P, Ni Mhurchu C. 2014. Systematic review and meta-analysis of the effect of increased vegetable and fruit consumption on body weight and energy intake. BMC Public Health 14:886.

Nafar M, Emam-Djomeh Z, Yousefi S, Hashemi Ravan M. 2013. An optimization study on the ultrasonic treatments for *Saccharomyces cerevisiae* inactivation in red grape juice with maintaining critical quality attributes. J Food Quality 36:269–81.

Nandi BK, Das B, Uppaluri R. 2012. Clarification of orange juice using ceramic membrane and evaluation of fouling mechanism. J Food Process Eng 353:403–23.

Naresh K, Varakumar S, Variyar PS, Sharma A, Reddy OVS. 2015. Effect of γ-irradiation on physico-chemical and microbiological properties of mango (*Mangifera indica* L.) juice from eight Indian cultivars. Food Biosci 12: 1–9.

Navarro JL, Izquierdo L, Carbonell JV, Sentandreu E. 2014. Effect of pH, temperature and maturity on pectinmethylesterase inactivation of citrus juices treated by high-pressure homogenization. LWT - Food Sci Technol 57:785–8.

Nayak CA, Valluri SS, Rastogi NK. 2011. Effect of high or low molecular weight of components of feed on transmembrane flux during forward osmosis. J Food Eng 106:48–52.

Nayak PK, Rayaguru K, Radha Krishnan K. 2017. Quality comparison of elephant apple juices after high-pressure processing and thermal treatment. J Sci Food Agric 975:1404–11.

Nourbakhsh H, Emam-Djomeh Z, Mirsaeedghazi H, Omid M, Moieni S. 2014. Study of different fouling mechanisms during membrane clarification of red plum juice. Int J Food Sci Technol 49:58–64.

Nuncio-Jáuregui N, Calín-Sánchez Á, Vázquez-Araújo L, Pérez-López AJ, Frutos-Fernández MJ, Carbonell-Barrachina ÁA. 2015. In: Preedy V, editor. Processing pomegranates for juice and impact on bioactive components. Processing and Impact on Active Components in Food. London: Academic Press. p 629–36.

Ochoa-Velasco CE, Guerrero Beltrán JA. 2013. Short-wave ultraviolet-C light effect on pitaya (*Stenocereus griseus*) juice inoculated with *Zygosaccharomyces bailii*. J of Food Eng 117:34–41.

Odriozola-Serrano I, Puigpinós J, Oliu GO, Herrero E, Martín-Belloso O. 2016. Antioxidant activity of thermal or non-thermally treated strawberry and mango juices by *Saccharomyces cerevisiae* growth based assays. LWT - Food Sci and Technol 74:55–61.

Onsekizoglu P, Savas Bahceci K, Acar MJ. 2010. Clarification and the concentration of apple juice using membrane processes: A comparative quality assessment. J Membrane Sci 352:160–5.

Onsekizoglu P. 2013. Production of high quality clarified pomegranate juice concentrate by membrane processes. J Membrane Science 442:264–271.

Ortuño C, Balaban M, Benedito J. 2014a. Modelling of the inactivation kinetics of *Escherichia coli*, *Saccharomyces cerevisiae* and pectin methylesterase in orange juice treated with ultrasonic-assisted supercritical carbon dioxide. J Supercrit Fluid 90:18–26.

Ortuño C, Quiles A, Benedito J. 2014b. Inactivation kinetics and cell morphology of *E. coli* and *S. cerevisiae* treated with ultrasound-assisted supercritical CO_2. Food Res Int 62:955–64.

Pala CU, Toklucu AK. 2011. Effect of UV-C light on anthocyanin content and other quality parameters of pomegranate juice. J Food Compos Anal 24:790–5.

Palgan I, Caminiti IM, Muñoz A, Noci F, Whyte P, Morgan DJ, Cronin DA, Lyng JG. 2011. Combined effect of selected non-thermal technologies on *Escherichia coli* and *Pichia fermentans* inactivation in an apple and cranberry juice blend and on product shelf life. Int J Food Microbiol 151:1–6.

Palgan I, Muñoz A, Noci F, Whyte P, Morgan DJ, Cronin DA, Lyng JG. 2012. Effectiveness of combined pulsed electric field (PEF) and manothermosonication (MTS) for the control of *Listeria innocua* in a smoothie type beverage. Food Control 25:621–5.

Pankaj SK, Wan Z, Colonna W, Keener KM. 2017. Effect of high voltage atmospheric cold plasma on white grape juice quality. J Sci Food Agric. 97:4016–21.

Pap N, Mahosenaho M, Pongrácz E, Mikkonen H, Jaakkola M, Virtanen V, Myllykoski L, Horváth-Hovorka Z, Hodúr C, Vatai G, Keiski RL. 2012. Effect of ultrafiltration on anthocyanin and flavonol content of blackcurrant juice (*Ribesnigrum*). Food Bioprocess Technol 5:921–8.

Pap N, Pongrácz E, Jaakkola M, Tolonen T, Virtanen V, Turkki A, Horváth-Hovorkad Z, Vatai G, Keiski RL. 2010. The effect of pre-treatment on the anthocyanin and flavonol content of black currant juice (*Ribesnigrum* L.) in concentration by reverse osmosis. J Food Eng 98: 429–36.

Park SH, Balasubramaniam VM, Sastry SK, Lee J. 2013. Pressure-ohmic-thermal sterilization: a feasible approach for the inactivation of *Bacillus amyloliquefaciens* and *Geobacillus stearothermophilus* spores. Innov Food Sci Emerg Technol 19:115–23.

Parker TL, Esgro ST, Miller SA, Myers LE, Meister RA, Toshkov SA, Engeseth NJ. 2010. Development of an optimised papaya pulp nectar using a combination of irradiation and mild heat. Food Chem 118:861–9.

Pataro G, De Lisi M, Donsì G, Ferrari G. 2014. Microbial inactivation of *E. coli* cells by a combined PEF-HPCD treatment in a continuous flow system. Innov Food Sci Emerg Technol 22:102–9.

Pataro G, Muñoz A, Palgan I, Noci F, Ferrari G, Lyng JG. 2011. Bacterial inactivation in fruit juices using a continuous flow pulsed light (PL) system. Food Res Int 44:1642–8.

Patil S, Valdramidis VP, Cullen PJ, Frias JM, Bourke P. 2010. Ozone inactivation of acid stressed *Listeria monocytogenes* and *Listeria innocua* in orange juice using a bubble column. Food Control 21:1723–30.

Patil S, Valdramidis VP, Tiwari BK, Cullen PJ, Bourke P. 2011. Quantitative assessment of the shelf life of ozonated apple juice. Eur Food Res Technol 232:469–77.

Patrignani F, Tabanelli G, Siroli L, Gardini F, Lanciotti R. 2013. Combined effects of high pressure homogenization treatment and citral on microbiological quality of apricot juice. Int J Food Microbiol 160: 273–81.

Patrignani F, Vannini L, Kamdem SL, Lanciotti R, Guerzoni ME. 2010. Potentialites of high pressure homogenization to inactivate *Zygosaccharomyces bailii* in fruit juices. J Food Sci 75:M116–20.

Patterson MF, McKay AM, Connolly M, Linton M. 2012. The effect of high hydrostatic pressure on the microbiological quality and safety of carrot juice during refrigerated storage. Food Microbiol 30:205–12.

Petrotos KB, Tsiadi AV, Poirazis E, Papadopoulos D, Petropakis H, Gkoutsidis P. 2010. A description of a flat geometry direct osmotic concentrator to concentrate tomato juice at ambient temperature and low pressure. J Food Eng 97:235–42.

Plaza L, Sánchez-Moreno C, De Ancos B, Elez-Martínez P, Martín-Belloso O, Cano MP. 2011. Carotenoid and flavanone content during refrigerated storage of orange juice processed by high-pressure, pulsed electric fields and low pasteurization. LWT-Food Sci Technol 44:834–9.

Porębska I, Sokołowska B, Skąpska S, Rzoska SJ. 2017. Treatment with high hydrostatic pressure and supercritical carbon dioxide to control *Alicyclobacillus acidoterrestris* spores in apple juice. Food Control 73: 24–30.

Pozderović A, Popović K, Pichler A, Jakobek L. 2016. Influence of processing parameters on permeate flow and retention of aroma and phenolic compounds in chokeberry juice concentrated by reverse osmosis. CYTA J Food 14:382–90.

Qin G, Lü X, Wei W, Li J, Cui R, Hu S. 2015. Microfiltration of kiwifruit juice and fouling mechanism using fly-ash-based ceramic membranes. Food Bioprod Process 96:278–84.

Queirós RP, Rainho D, Santos MD, Fidalgo LG, Delgadillo I, Saraiva JA. 2015. High pressure and thermal pasteurization effects on sweet cherry juice microbiological stability and physicochemical properties. High Pressure Res 35:69–77.

Queiroz C, Moreira CFF, Lavinas FC, Lopes MLM, Fialho E, Valente-Mesquita VL. 2010. Effect of high hydrostatic pressure on phenolic compounds, ascorbic acid and antioxidant activity in cashew apple juice. High Pressure Res 30:507–13.

Quintão-Teixeira LJ, Soliva-Fortuny R, Mota Ramos A, Martín-Belloso O. 2013. Kinetics of peroxidase inactivation in carrot juice treated with pulsed electric fields. J Food Sci 78:E222–8.

Quist-Jensen CA, Macedonio F, Conidi C, Cassano A, Aljlil S, Alharbi OA, Drioli E. 2016. Direct contact membrane distillation for the concentration of clarified orange juice. J Food Eng 187:37–43.

Rácz C, Alam MR, Arekatte ChK, Albert K, Papp N, Stefanovits-Bányai É, Russo P, Di Matteo M, Vatai Gy. 2014. Potassium acetate solution as a promising option to osmotic distillation for sour cherry (*Prunuscerasus* L.) juice concentration. Acta Aliment 43:11–23.

Rai P, Majumdar GC, Dasgupta S, De S. 2010. Flux enhancement during ultrafiltration of depectinized mosambi (*Citrus sinensis* [L] Osbeck) juice. J Food Process Eng 33:554–67.

Ramachandran P, Nagarajan S. 2014. Quality characteristics, nutraceutical profile, and storage stability of aloe gel-papaya functional beverage blend. Int J Food Sci ID 847013.

Rameshkumar A, Sivasudha T, Jeyadevi R, Arul Ananth DA, Pradeepha G. 2012. Effect of environmental factors [air and UV-C irradiation] on some fresh fruit juices. Eur Food Res Technol 234:1063–70.

Rao L, Guo X, Pang X, Tan X, Liao X, Wu J. 2014. Enzyme activity and nutritional quality of peach (*Prunus persica*) juice: effect of high hydrostatic pressure. Int J Food Prop 17:1406–17.

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 44:1875–87.

Rawson A, Tiwari BK, Patras A, Brunton N, Brennan C, Cullen PJ, O'Donnell C. 2011b. Effect of thermosonication on bioactive compounds in watermelon juice. Food Res Int 44:1168–73.

Razi B, Aroujalian A, Fathizadeh M. 2012. Modeling of fouling layer deposition in cross-flow microfiltration during tomato juice clarify. Food and Bioprod Process 90:841–8.

Rekhy R, McConchie R. 2014. Promoting consumption of fruit and vegetables for better health. Have campaigns delivered on the goals? Appetite 79:113–23.

Režek Jambrak A, Šimunek M, Evačić S, Markov K, Smoljanić G, Frece J. 2017. Influence of high power ultrasound on selected moulds, yeasts and Alicyclobacillus acidoterrestris in apple, cranberry and blueberry juice and nectar. Ultrasonics. https://doi.org/10.1016/j.ultras.2017.02.011

Rezzadori K, Serpa L, Penha FM, Petrus RR, Petrus JCC. 2014. Crossflow microfiltration of sugarcane juice-effects of processing conditions and juice quality. Food Sci Technol 34:210–7.

Rivas A, Sansano S, Pina Pérez MC, Martinez A, Rodrigo D. 2016. Antimicrobial effect of *Stevia rebaudiana* Bertoni against *Listeria monocytogenes* in a beverage processed by pulsed electric fields (PEFs): Combined effectiveness. IFMBE Proceedings 53:43–46.

Rodríguez-Roque MJ, de Ancos B, Sánchez-Moreno C, Cano MP, Elez-Martínez P, Martín-Belloso O. 2014. Impact of food matrix and processing on the *in vitro* bioaccessibility of vitamin C, phenolic compounds,

and hydrophilic antioxidant activity from fruit juice-based beverages. J Funct Foods 14:33–43.

Roig-Sagués AX, Asto E, Engers I, Hernández-Herrero MM. 2015. Improving the efficiency of ultra-high pressure homogenization treatments to inactivate spores of *Alicyclobacillus* spp. in orange juice controlling the inlet temperature. LWT - Food Sci Technol 63:866–71.

Rojas ML, Leite TS, Cristianini M, Alvim ID, Augusto PED. 2016. Peach juice processed by the ultrasound technology: Changes in its microstructure improve its physical properties and stability. Food Res Int 82: 22–33.

Saad SM, AbdElaleem IM, Foda MF, Eissa HA, Abdelmoniem GM, Ibrahim WA. 2013. Effects of thermosonication on apple and guava juices quality. J Appl Sci Res 98:5323–36.

Saeeduddin M, Abid M, Jabbar S, Hu B, Hashim MM, Khan MA, Xie M, Wu T, Zeng X. 2016. Physicochemical parameters, bioactive compounds and microbial quality of sonicated pear juice. Int J Food Sci Technol 51:1552–9.

Saeeduddin M, Abid M, Jabbar S, Wu T, Hashim MM, Awad FN, Hu B, Lei S, Zeng X. 2015.Quality assessment of pear juice under ultrasound and commercial pasteurization processing conditions. LWT - Food Sci Technol 64:452–8.

Sagu ST, Karmakar S, Nso EJ, De S. 2014a. Primary clarification of banana juice extract by centrifugation and microfiltration. Sep Sci Technol 49:1156–69.

Sagu ST, Karmakar S, Nso EJ, Kapseu C, De S. 2014b. Ultrafiltration of banana (*Musa acuminata*) juice using hollow fibers for enhanced shelf life. Food Bioproc Technol 7:2711–22.

Saikia S, Mahnot NK, Mahanta CL. 2015. A comparative study on the effect of conventional thermal pasteurisation, microwave and ultrasound treatments on the antioxidant activity of five fruit juices. Food Sci Technol Int 22:288–301.

Saldaña G, Puértolas E, Monfort S, Raso J, Alvarez I. 2011. Defining treatment conditions for pulsed electric field pasteurization of apple juice. Int J Food Microbiol 151:29–35.

Salvia-Trujillo L, Morales-de la Peña M, Rojas-Graü MA, Martín-Belloso O. 2011. Microbial and enzymatic stability of fruit juice-milk beverages treated by high intensity pulsed electric fields or heat during refrigerated storage. Food Control 22:1639–46.

Samani BH, Khoshtaghaza MH, Lorigooini Z, Minaei S, Zareiforoush H. 2015a. Analysis of the combinative effect of ultrasound and microwave power on *Saccharomyces cerevisiae* in orange juice processing. Innov Food Sci Emerg Technol 32:110–5.

Samani BH, Khoshtaghaza M, Minaee S, Abbasi S. 2015b. Modeling the simultaneous effects of microwave and ultrasound treatments on sour cherry juice using response surface methodology. J Agric Sci Technol 17: 837–46.

Samani BH, Khoshtghaza MH, Minaee S, Abbasi S. 2013. Effect of ultrasonic waves on pasteurization of sour cherry juice. Int J Biosci 3:193–200.

Sánchez-Rubio M, Taboada-Rodríguez A, Cava-Roda R, López-Gómez A, Marín-Iniesta F. 2016. Combined use of thermo-ultrasound and cinnamon leaf essential oil to inactivate *Saccharomyces cerevisiae* in natural orange and pomegranate juices. LWT - Food Sci Technol 73:140–6.

Sango DM, Abela D, Mcelhatton A, Valdramidis VP. 2014. Assisted ultrasound applications for the production of safe foods. J Appl Microbiol 116:1067–83.

Sankhla S, Chaturvedi A, Kuna A, Dhanlakshmi K. 2012. Preservation of sugarcane juice using hurdle technology. Sugar Technol 14:26–39.

Sant'Anna V, Gurak PD, de Vargas NS, da Silva MK, Marczak LDFM, Tessaro IC. 2016. Jaboticaba (*Myrciaria jaboticaba*) juice concentration by forward osmosis. Sep Sci Technol 51:1708–15.

Sant'Anna V, Marczak LDF, Tessaro IC. 2012. Membrane concentration of liquid foods by forward osmosis: process and quality view. J Food Eng 111:483–9.

Santhirasegaram V, Razali Z, George DS, Somasundram C. 2015a. Comparison of UV-C treatment and thermal pasteurization on quality of Chokanan mango (*Mangiferaindica* L.) juice. Food Bioprod Process 94:313–21.

Santhirasegaram V, Razali Z, George DS, Somasundram C. 2015b. Effects of thermal and non-thermal processing on phenolic compounds, antioxidant activity and sensory attributes of chokanan mango (*Mangifera indica* L.) juice. Food and Bioprocess Technol 8:2256–67.

Santhirasegaram V, Razali Z, Somasundram C. 2015c. Effects of sonication and ultraviolet C treatment as a hurdle concept on quality attributes of Chokanan mango (*Mangiferaindica* L.) juice. Food Sci Technol Int. 21:232–41.

Sarkar B. 2015. Enhanced cross-flow ultrafiltration of apple juice using electric field. J Food Process Pres 39:1372–84.

Savaş Bahçeci K, Gül Akillioğlu H, Gökmen V. 2015. Osmotic and membrane distillation for the concentration of tomato juice: Effects on quality and safety characteristics. Innov Food Sci Emerg Technol 31: 131–8.

Scolari G, Zacconi C, Busconi M, Lambri M. 2015. Effect of the combined treatments of high hydrostatic pressure and temperature on *Zygosaccharomyces bailii* and *Listeria monocytogenes* in smoothies. Food Control 47:166–74.

Sew CC, MohdGhazali H, Martín-Belloso O, Noranizan MA. 2014. Effects of combining ultraviolet and mild heat treatments on enzymatic activities and total phenolic contents in pineapple juice. Innov Food Sci Emerg Technol 26:511–6.

Shah NNAK, Shamsuddin R, Rahman RA, Adzahan NM. 2014. Effects of physicochemical characteristics of pummelo fruit juice towards UV inactivation of *Salmonella typhimurium*. Agric Sci Proc 2:43–52.

Shah NNAK, Shamsuddin R, Rahman RA, Adzahan NM., 2016. Fruit juice production using ultraviolet pasteurization: a review. Beverages 2:22.

Shahbaz HM, Yoo S, Seo B, Ghafoor K, Kim JU, Lee DU, Park J. 2016.Combination of TiO_2-UV photocatalysis and high hydrostatic pressure to inactivate bacterial pathogens and yeast in commercial apple juice. Food Bioproc Technol 9:182–90.

Shaheer CA, Hafeeda P, Kumar R, Kathiravan T, Kumar D, Nadanasabapathi S. 2014. Effect of thermal and thermosonication on anthocyanin stability in jamun (*Eugenia jambolana*) fruit juice. Int Food Res J 21:2189–94.

Shamsudin R, MohdAdzahan N, Pui Yee Y, Mansor A. 2014. Effect of repetitive ultraviolet irradiation on the physico-chemical properties and microbial stability of pineapple juice. Innov Food Sci Emerg Technol 23:114–20.

Shi XM, Zhang GJ, Wu XL, Li YX, Ma Y, Shao XJ. 2011. Effect of low-temperature plasma on microorganism inactivation and quality of freshly squeezed orange juice. IEEE T Plasma Sci 39:1591–7.

Šimunek M, Jambrak AR, Dobrović S, Herceg Z, Vukušić T. 2014. Rheological properties of ultrasound treated apple, cranberry and blueberry juice and nectar. J Food Sci Technol 51:3577–93.

Šimunek M, Jambrak AR, Petrović M, Juretić H, Major N, Herceg Z, Hruškar M, Vukušić T. 2013. Aroma profile and sensory properties of ultrasound-treated apple juice and nectar. Food Technol Biotech 51:101–11.

Siwach R. 2012. Pectin methylesterase inactivation in Mosambi juice. J Life Sci 4:81–5.

Skąpska S, Marszałek K, Woźniak L, Zawada K, Wawer I. 2016. Aronia dietary drinks fortified with selected herbal extracts preserved by thermal pasteurization and high pressure carbon dioxide. LWT - Food Sci Technol 30:1–4.

Sokołowska B, Skąpska S, Fonberg-Broczek M, Niezgoda J, Chotkiewicz M, Dekowska A, Rzoska SJ. 2012. The combined effect of high pressure and nisin or lysozyme on the inactivation of *Alicyclobacillus acidoterrestris* spores in apple juice. High Pressure Res 32:119–27.

Sokołowska B, Skąpska S, Fonberg-Broczek M, Niezgoda J, Chotkiewicz M, Dekowska A, Rzoska SJ. 2013a. Factors influencing the inactivation of *Alicyclobacillus acidoterrestris* spores exposed to high hydrostatic pressure in apple juice. High Pressure Res 33:73–82.

Sokołowska B, Skapska S, Fonberg-Broczek M, Niezgoda J, Rutkowska M, Chotkiewicz M, Dekowska A, Rzoska SJ. 2013b. The effect of high hydrostatic pressure on the survival of *Saccharomyces cerevisiae* in model suspensions and beetroot juice. High Pressure Res 33:165–71.

Song HP, Kim BD, Shin EH, Song DS, Lee HJ, Kim DH. 2010. Effects of gamma irradiation on the microbiological and general quality characteristics of fresh yam juice. Korean J Food Preserv 17:494–9.

Song WJ, Shin JY, Ryu S, Kang DH. 2015a.Inactivation of *Escherichia coli* O157:H7, *Salmonella* Typhimurium and *Listeria monocytogenes* in apple juice at different pH levels by gaseous ozone treatment. J Appl Microbiol 119:465–74.

Song WJ, Sung HJ, Kang DH. 2015b. Inactivation of *Escherichia coli* O157:H7 and *Salmonella* Typhimurium in apple juices with different soluble solids content by combining ozone treatment with mild heat. J Appl Microbiol 118:112–22.

Sotoft LF, Christensen KV, Andrésen R, Norddahl B. 2012. Full scale plant with membrane based concentration of blackcurrant juice on the basis of laboratory and pilot scale tests. Chem Eng Process 54:12–21.

Souza ALR, Pagani MM, Dornier M, Gomes FS, Tonon RV, Cabral LMC. 2013. Concentration of camu–camu juice by the coupling of reverse osmosis and osmotic evaporation processes. J Food Eng 119:7–12.

Spilimbergo S, Ciola L. 2010. Supercritical CO_2 and N_2O pasteurisation of peach and kiwi juice. Int J Food Sci Technol 45:1619–25.

Suárez-Jacobo A, Saldo J, Gervilla R. 2014. Influence of high-pressure and ultra-high-pressure homogenization on antioxidants in fruit juice. In: Preedy V, editor. Processing and impact on antioxidants in beverages. Oxford: Academic Press Elsevier. p 185–93.

Sung HJ, Song WJ, Kim KP, Ryu S, Kang DH. 2014. Combination effect of ozone and heat treatments for the inactivation of *Escherichia coli* O157:H7, *Salmonella* Typhimurium, and *Listeria monocytogenes* in apple juice. Int J Food Microbiol. 171:147–53.

Surowsky B, Fröhling A, Gottschalk N, Schlüter O, Knorr D. 2014. Impact of cold plasma on *Citrobacter freundii* in apple juice: inactivation kinetics and mechanisms. Int J Food Microbiol 174:63–71.

Swada JG, Keeley CJ, Ghane MA, Engeseth NJ. 2016a. Relationship between pulp structure breakdown and nutritional value of papaya (*Carica papaya*) and strawberry (*Fragaria* x *ananassa*) nectars using alternative thermal and non-thermal processing techniques. J Sci Food Agric 96: 2514–23.

Swada JG, Keeley CJ, Ghane MA, Engeseth NJ. 2016b. Synergistic potential of papaya and strawberry nectar blends focused on specific nutrients and antioxidants using alternative thermal and non-thermal processing techniques. Food Chem 199:87–95.

Swami Hulle NR, Kaushik N, Rao PS. 2015. Effect of high pressure processing on rheological properties, pectinmethyl esterase activity and microbiological characteristics of aloe vera (*Aloe barbadensis* Miller) juice. Int J Food Prop 18:1597–612.

Swami Hulle NR, Rao PS. 2016. Effect of high pressure and thermal processing on quality changes of aloe vera-litchi mixed beverage (ALMB) during storage. J Food Sci Technol 53:359–69.

Tao Y, Sun DW, Górecki A, Błaszczak W, Lamparski G, Amarowicz R, Fornal J, Jeliński T. 2012. Effects of high hydrostatic pressure processing on the physicochemical and sensorial properties of a red wine. Innov Food Sci Emerg Technol 16:409–16.

Tejada-Ortigoza V, Escobedo-Avellaneda Z, Valdez-Fragoso A, Mújica-Paz H, Welti-Chanes J. 2015. Combined effect of high hydrostatic pressure and mild heat treatments on pectin methylesterase (PME) inactivation in comminuted orange. J Sci Food Agric 95:2438–44.

Tennant DR, Davidson J, Day AJ. 2014. Phytonutrient intakes in relation to European fruit and vegetable consumption patterns observed in different food surveys. British J Nutr 112:1214–25.

Timmermans RA, Nederhoff AL, Nierop Groot MN, van Boekel MA, Mastwijk HC. 2016. Effect of electrical field strength applied by PEF processing and storage temperature on the outgrowth of yeasts and moulds naturally present in a fresh fruit smoothie. Int J Food Microbiol 230:21–30.

Toepfl S. 2012. Pulsed electric field food processing-industrial equipment design and commercial applications. Stewart Postharvest Rev 8:1–7.

Tola YB, Ramaswamy HS. 2014. Combined effects of high pressure, moderate heat and pH on the inactivation kinetics of *Bacillus licheniformis* spores in carrot juice. Food Res Int 62:50–8.

Tomadoni B, Cassani L, Ponce A, Moreira MR, Agüero MV. 2016. Optimization of ultrasound, vanillin and pomegranate extract treatment for shelf-stable unpasteurized strawberry juice. LWT - Food Sci Technol 72:475–84.

Tomadoni B, Moreira MDR, Espinosa JP, Ponce A. 2017. Individual and combined effects of pomegranate extract and ultrasonic treatments on kiwifruit juice quality parameters. J Food Process Eng 40:e12339.

Torlak E. 2014. Efficacy of ozone against *Alicyclobacillus acidoterrestris* spores in apple juice. Int J Food Microbiol 172:1–4.

Tremarin A, Brandão TRS, Silva CLM. 2017. Inactivation kinetics of *Alicyclobacillus acidoterrestris* in apple juice submitted to ultraviolet radiation. Food Control 73:18–23.

Tribst AAL, Franchi MA, de Massaguer PR, Cristianini M. 2011. Quality of mango nectar processed by high-pressure homogenization with optimized heat treatment. J Food Sci 76:M106–10.

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 paradise* Macfad) juice. Innov Food Sci Emerg Technol 18:7–14.

Ukuku DO, Geveke DJ, Cooke PH. 2012. Effect of thermal and radio frequency electric fields treatments on *Escherichia coli* bacteria in apple juice. J Microb Biochem Technol 4:76–81.

Ukuku DO, Geveke DJ. 2010. A combined treatment of UV-light and radio frequency electric field for the inactivation of *Escherichia coli* K-12 in apple juice. Int J Food Microbiol 138:50–5.

Usaga J, Churey JJ, Padilla-Zakour OI, Worobo RW. 2014. Determination of the validation frequency for commercial UV juice processing units. J Food Protect 77:2076–80.

Usaga J, Manns DC, Moraru CI, Worobo RW, Padilla-Zakour OI. 2017.Ascorbic acid and selected preservatives influence effectiveness of UV treatment of apple juice. LWT - Food Sci Technol 75:9–16.

Valero M, Vegara S, Martí N, Saura D. 2014. Clarification of pomegranate juice at industrial scale. J Food Process Technol 5:5.

Vallverdú-Queralt A, Odriozola-Serrano I, Oms-Oliu G, Lamuela-Raventós RM, Elez-Martínez P, Martín-Belloso O. 2013. Impact of high-intensity pulsed electric fields on carotenoids profile of tomato juice made of moderate-intensity pulsed electric field-treated tomatoes. Food Chem 141:3131–8.

Velázquez-Estrada RM, Hernández-Herrero MM, López-Pedemonte TJ, Briñez-Zambrano WJ, Guamis-López B, Roig-Sagués AX. 2011. Inactivation of *Listeria monocytogenes* and *Salmonella enteric* serovar Senftenberg 775W inoculated into fruit juice by means of ultrahigh pressure homogenization. Food Control 22:313–7.

Verbeyst L, Hendrickx M, Van Loey A. 2012. Characterisation and screening of the process stability of bioactive compounds in red fruit paste and red fruit juice. Eur Food Res Technol 234:593–605.

Viedma PM, López AS, Nabil Omar BEN, Abriouel H, López RL, Martín-Belloso O, Gálvez A. 2010. Increased inactivation of exopolysaccharide-producing *Pediococcus parvulus* in apple juice by combined treatment with enterocin AS-48 and high-intensity pulsed electric field. J Food Protect 73:39–43.

Vivekanand V, Iyer M, Ajlouni S. 2012. Clarification and stability enhancement of pear juice using loose nanofiltration. J Food Process Technol 3:162.

Vladisavljević GT, Vukosavljević P, Veljović MS. 2013. Clarification of red raspberry juice using microfiltration with gas backwashing: a viable strategy to maximize permeate flux and minimize a loss of anthocyanins. Food and Bioprod Process 91:473–80.

Walkling-Ribeiro M, Noci F, Cronin DA, Lyng JG, Morgan DJ. 2010. Shelf life and sensory attributes of a fruit smoothie-type beverage processed with moderate heat and pulsed electric fields. LWT - Food Sci Technol 43:1067–73.

Wang C, Lin Y, Ramaswamy HS, Ge L, Hu F, Zhu S, Yu Y. 2015. Storage stability of chinese bayberry juice after high pressure or thermal treatment. J Food Process Pres 39:2259–66.

Wang C, Mao M, Hu F, Yu Y, He J, Zhu S. 2013. Comparison of sensory quality between subjective evaluation and instrument detection for cucumber juice with high pressure processing and heat treatment. TCSAE 29:278–86.

Wang L, Pan J, Xie H, Yang Y, Zhou D, Zhu Z. 2012a. Pasteurization of fruit juices of different pH values by combined high hydrostatic pressure and carbon dioxide. J Food Protect 75:1873–7.

Wang Y, Liu F, Cao X, Chen F, Hu X, Liao X. 2012b. Comparison of high hydrostatic pressure and high temperature short time processing on quality of purple sweet potato nectar. Innov Food Sci Emerg Technol 16: 326–34.

Won JS, Kim MH, Han GJ, Noh BS, Min SC. 2015. Preservation of strawberry juice by dynamic high-pressure processing. Korean J Food Sci Technol 47:480–5.

Wong E, Vaillant F, Chaves-Olarte E. 2010a. Synergistic effect of sonication and high osmotic pressure enhances membrane damage and viability loss of *Salmonella* in orange juice. Food Res Int 45:1072–9.

Wong E, Vaillant F, Pérez A. 2010b. Osmosonication of blackberry juice: impact on selected pathogens, spoilage microorganisms, and main quality parameters. J Food Sci 75:M468–74.

Wootton-Beard PC, Ryan L. 2011. Improving public health? The role of antioxidant-rich fruit and vegetable beverages. Food Res Int 44: 3135–48.

Worametrachanon S, Techarang J, Chaikham P, Chunthanom P. 2014. Evaluation of quality changes of pressurized and pasteurized herbal-plant beverages during chilled storage. Int Food Res J 21:2077–83.

Xu W-W, Liao X-J. 2011. Effects of high hydrostatic pressure (HHP) processing on microbial inactivation and quality of strawberry nectar. Food Sci 32:28–34.

Xu Z, Lin T, Wang Y, Liao X. 2015. Quality assurance in pepper and orange juice blend treated by high pressure processing and high temperature short time treatment. Innov Food Sci Emerg Technol 31:28–36.

Yazdanshenas M, Tabatabaee-Nezhad SAR, Soltanieh M, Roostaazad R, Khoshfetrat AB. 2010. Contribution of fouling and gel polarization during ultrafiltration of raw apple juice at industrial scale. Desalination 258:194–200.

Yin F, Zhu Y, Koutchma T, Gong J. 2015. Inactivation and potential reactivation of pathogenic *Escherichia coli* O157:H7 in apple juice following ultraviolet light exposure at three monochromatic wavelengths. Food Microbiol 46:329–35.

Yoo S, Ghafoor K, Kim JU, Kim S, Jung B, Lee DU, Park J. 2015. Inactivation of *Escherichia coli* O157:H7 on orange fruit surfaces and in juice using photocatalysis and high hydrostatic pressure. J Food Protect 78:1098–105.

Yu LJ, Rupasinghe HPV. 2013. Improvement of cloud stability, yield and β-carotene content of carrot juice by process modification. Food Sci Technol Int 19:399–406.

Yu Y, Wu J, Xu Y, Xiao G, Zou B. 2016. Effect of high pressure homogenization and dimethyl dicarbonate (DMDC) on microbial and physicochemical qualities of mulberry juice. J Food Sci 81: M702–8.

Yu Y, Xiao G, Wu J, Xu Y, Tang D, Chen Y, Wen J, Fu M. 2013. Comparing characteristic of banana juices from banana pulp treated by high pressure carbon dioxide and mild heat. Innov Food Sci Emerg Technol 18:95–100.

Yu Y, Xu Y, Wu J, Xiao G, Fu M, Zhang Y. 2014. Effect of ultra-high pressure homogenisation processing on phenolic compounds, antioxidant capacity and anti-glucosidase of mulberry juice. Food Chem 153:114–20.

Yuk HG, Geveke DJ. 2011. Non thermal inactivation and sublethal injury of *Lactobacillus plantarum* in apple cider by a pilot plant scale continuous supercritical carbon dioxide system. Food Microbiol 28:377–83.

Yuk HG, Sampedro F, Fan X, Geveke DJ. 2014. Non thermal processing of orange juice using a pilot-plant scale supercritical carbon dioxide system with a gas–liquid metal contactor. J Food Process Pres 38:630–8.

Zacconi C, Giosuè S, Marudelli M, Scolari G. 2015. Microbiological quality and safety of smoothies treated in different pressure–temperature domains: effects on indigenous fruit microbiota and *Listeria monocytogenes* and their survival during storage. Eur Food Res Technol 241:317–28.

Zambra C, Romero J, Pino L, Saavedra A, Sanchez J. 2015. Concentration of cranberry juice by osmotic distillation process. J Food Eng 144:58–65.

Zhang QA, Shen Y, Fan XH, García Martín JF. 2016. Preliminary study of the effect of ultrasound on physicochemical properties of red wine. CYTA J Food 14:55–64.

Zhang Y, Gao B, Zhang M, Shi J, Xu Y. 2010. Pulsed electric field processing effects on physicochemical properties, flavor compounds and microorganisms of longan juice. J Food Process Pres 34:1121–38.

Zhao D, Barrientos JU, Wang Q, Markland SM, Churey JJ, Padilla-Zakour OI, Worobo RW, Kniel KE, Moraru CI. 2015a. Efficient reduction of pathogenic and spoilage microorganisms from apple cider by combining microfiltration with UV treatment. J Food Protect 78:716–22.

Zhao D, Lau E, Huang S, Moraru CI. 2015b. The effect of apple cider characteristics and membrane pore size on membrane fouling. LWT - Food Sci Technol 64:974–9.

Zhao L, Wang S, Liu F, Dong P, Huang W, Xiong L, Liao X. 2013. Comparing the effects of high hydrostatic pressure and thermal pasteurization combined with nisin on the quality of cucumber juice drinks. Innov Food Sci Emerg Technol 17:27–36.

Zhao L, Wang Y, Hu X, Sun Z, Liao X. 2016. Korla pear juice treated by ultrafiltration followed by high pressure processing or high temperature short time. LWT - Food Sci Technol 65:283–9.

Zhao L, Wang Y, Qiu D, Liao X. 2014. Effect of ultrafiltration combined with high-pressure processing on safety and quality features of fresh apple juice. Food Bioprocess Technol 7:3246–58.

Zheng X, Yu Y, Xiao G, Xu Y, Wu J, Tang D, Zhang Y. 2014. Comparing product stability of probiotic beverages using litchi juice treated by high hydrostatic pressure and heat as substrates. Innov Food Sci Emerg Technol 23:61–7.

Zhu Z, Mhemdi H, Ding L, Bals O, Jaffrin MY, Grimi N, Vorobiev E. 2015. Dead-end dynamic ultrafiltration of juice expressed from electroporated sugar beets. Food Bioprocess Technol 8:615–22.

Zhu J, Wang Y, Li X, Li B, Liu S, Chang N, Jie D, Ning C, Gao H, Meng X 2017. Combined effect of ultrasound, heat, and pressure on *Escherichia coli* O157:H7, polyphenol oxidase activity, and anthocyanins in blueberry (*Vaccinium corymbosum*) juice. Ultrason Sonochem 37:251–9.

Zinoviadou KG, Galanakis CM, Brnčić M, Grimi N, Boussetta N, Mota MJ, Saraiva JA, Patras A, Tiwari B, Barba FJ. 2015. Fruit juice sonication: implications on food safety and physicochemical and nutritional properties. Food Res Int 77:743–52.

Zong W, Duan J, Zhao G. 2015. Effects of dense phase-CO_2 treatments on microflora, enzymes and browning of chinese winter jujube juice. Adv J Food Sci Technol 7:681–4.

Zou H, Lin T, Bi X, Zhao L, Wang Y, Liao X. 2016. Comparison of high hydrostatic pressure, high-pressure carbon dioxide and high-temperature short-time processing on quality of mulberry juice. Food Bioprocess Technol 9:217–31.

Zulueta A, Barba FJ, Esteve MJ, Frígola A. 2013. Changes in quality and nutritional parameters during refrigerated storage of an orange juice–milk beverage treated by equivalent thermal and non-thermal processes for mild pasteurization. Food Bioprocess Technol 6:2018–30.

