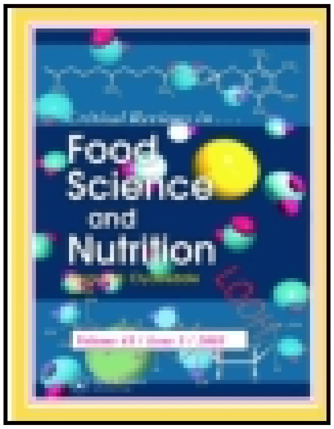

Critical Reviews in Food Science and Nutrition
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/bfsn20

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

Cecilia Jiménez-Sánchez[ab], Jesús Lozano-Sánchez[abc], Antonio Segura-Carretero[ab] & Alberto Fernández-Gutiérrez[ab]

[a] Department of Analytical Chemistry, University of Granada. Avda. Fuentenueva s/n, 18071, Granada, Spain

[b] Research and Development of Functional Food Centre (CIDAF), PTS Granada, Avda. Del Conocimiento s/n., Edificio BioRegión, 18016, Granada, Spain

[c] Department of Agricultural and Food Sciences, Alma Mater Studiorum- University of Bologna, Italy

Accepted author version posted online: 20 Apr 2015.

Review: 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

Jiménez-Sánchez, Cecilia[1,2]; Lozano-Sánchez, Jesús[1,2, 3]; Segura-Carretero, Antonio[1,2] and Fernández-Gutiérrez, Alberto[1,2]

1 Department of Analytical Chemistry, University of Granada. Avda. Fuentenueva s/n 18071 Granada, Spain

2 Research and Development of Functional Food Centre (CIDAF), PTS Granada, Avda. Del Conocimiento s/n., Edificio BioRegión, 18016 Granada, Spain

3 Department of Agricultural and Food Sciences, Alma Mater Studiorum- University of Bologna, Italy

Abstract

Traditional thermal techniques may cause losses in nutritional quality and phytochemical contents, and also in physicochemical, rheological, and organoleptic properties of processed fruit juices. This article provides an overview of the effect on these quality by the use of alternatives to traditional thermal treatments in fruit-juice processing, for three key operations in fruit-juice production such as microbial inactivation, enzyme inactivation, and juice-yield improvement. These alternatives are UV light, high-intensity light pulses, ɔ-irradiation, pulsed electric fields, radiofrequency electric fields, ohmic heating, microwave heating, ultrasound, high hydrostatic pressure, supercritical carbon dioxide, ozonation, and flash-vacuum expansion. Although alternatives to heat treatments seem to be less detrimental than the thermal treatment, there are many parameters and conditions that influence the output, as well as the nature of the juice itself, hampering comparisons between different studies. Additionally, future research should focus on understanding the mechanisms underlying the changes in the overall quality of fruit juices, and also on scaled-up processes, process design, and optimization that need to be deal with in detail to maximize their potential as alternative non-thermal technologies in fruit-juice processing while maintaining fruit-juice attributes to the maximum.

Keywords

Polyphenols, carotenoids, vitamin C, color, flavor, viscosity

1. Introduction

Today, consumer habits are changing with increasing demands for fresh-like products. Thus, fruit-juice industries have directed their studies to the search for alternative processing technologies in order to produce foods with a minimum of changes induced by the technologies themselves (Velázquez-Estrada et al.,et al.,, 2012).

It is well established that traditional thermal techniques can extend the shelf life of juices, ensuring their safety, and also maximize performance in fruit-juice processing. However, they may cause losses in nutritional, physicochemical, rheological, and organoleptic parameters (Gómez et al.,et al.,, 2011). Growing interest in a healthy diet and a better quality of life, together with a general knowledge linking phytochemical-containing fresh food and a protective role against chronic diseases such as coronary heart disease, cancer, and others (Mullen et al.,et al.,, 2007) point out the importance of preserving nutritional and phytochemical quality of fruit juices. Similarly, physicochemical attributes of fruit juices such as pH, Brix degree, or cloudiness determine their stability and storage ability, highlighting the importance of producing a stable product able to meet the requirements of an increasingly demanding market. It is generally believed that food texture and rheology are major determinants of consumer acceptance and preference, and the rheological characterization of food is also important for the design of unit operations, process optimization, and high-quality product assurance (Ibarz. 2003, Rao. 1999). Finally, the preservation of organoleptic attributes is crucial, as products are designed to please a more and more discerning consumer palate.

 ACCEPTED MANUSCRIPT

To overcome these difficulties, the fruit-juice-processing industry over the years has introduced novel technologies to extend shelf life, ensure safety, improve quality, and appeal to consumer perception without any adverse effect or damage on quality parameters of the juice (Abid et al., 2013). These technologies are ñnon-thermalò processing technologies intended to achieve similar microbial and enzymatic inactivation, and yield enhancement with reduced or no application of heat (Noci et al., 2008), and they have been under investigation to evaluate their potential as an alternative or as a complementary process to conventional thermal treatments (Heinz et al., 2003, Stewart et al., 2002). Consequently, an understanding of the effects that these alternative technologies, meant to replace heat treatments, exert on the quality attributes of juices becomes vital in order to design and optimize technological parameters in an effort to produce high-standard products.

In this context, the present work provides an overview of the impact of three key processes in fruit-juice production in fruit-juice preparation: microbial inactivation, enzyme inactivation, and juice-yield enhancement on the composition, phytochemical content and physicochemical, rheological and organoleptic properties of fruit juices, these being considered essential quality parameters. The technologies examined include UV light, high-intensity light pulses (HILP), ɔ-irradiation, pulsed electric fields (PEF), radiofrequency electric fields (RFEF), ohmic heating (OH), microwave heating (MH), ultrasound (US), high hydrostatic pressure (HHP), supercritical carbon dioxide (SC-CO_2), ozonation, and flash-vacuum expansion (FVE).

2. Effect of technological processing on the composition of fruit juices

In this section, carbohydrates, amino acids, proteins, lipids, and vitamins are reviewed.

 ACCEPTED MANUSCRIPT

2.1. Carbohydrates

Regarding radiation treatments, fructose has shown significant reactivity during ultraviolet light (UV, 254 nm) processing of fruit juices that can adversely affect product quality. Elsinghorst and Tikekar (2014) demonstrated that this reactivity of fructose is due to the oxidative nature of products formed from UV induced photolysis of fructose. On the contrary, Feng et al., (2013), and Falguera et al., (2011) confirmed that there is not an effect on watermelon and apples juices respectively

Electrical treatments such as PEF have not been reported to affect the concentrations of glucose, fructose, or sucrose at different field strengths (Schilling et al., 2007, Vervoort et al., 2011). Similarly, the pectin contents of the juices were not diminished, amounting to 1.1 g galacturonic acid/L in apple juice extraction on the laboratory scale (Schilling et al., 2007, Schilling et al., 2008).

On the other hand, microwave treatments have led to an effective extraction of pectins (Cendres et al., 2012) and also to an increased pectin solubilization (Igual et al., 2010a).

Other types of treatment such as US have resulted in a significant increase in sucrose (53.60%) and glucose (4.24%) concentrations in cantaloupe juices, when compared to non-treated samples (Fernandes et al., 2009). These results agree with previous researchers, who have reported that US promotes high extractability for sugars (Lieu and Le. 2010).

HHP processing has been reported to exert no effect on sugar composition (Vervoort et al., 2011). Similarly, no significant differences were detected for glucose, fructose, or sucrose after ozone treatment of apple cider (Choi and Nielsen. 2005).

 ACCEPTED MANUSCRIPT

And finally, FVE has shown an effect on carbohydrates of fruit juices. Two carbohydrates fractions have been studied in FVE passion fruit puree: the destarched alcohol-insoluble residue and water-soluble polysaccharides. The former from the vacuum-expanded fruit puree was richer in cellulose and xylose-containing polysaccharides and poorer in uronic-acid-containing polysaccharides than that of reference and steam-heated puree. Other neutral sugars were present in similar proportions. The latter were mainly pectic substances with dominant proportions of galacturonic acid highly esterified with methanol, while the reference-fruit puree had a different composition with a lower level of galacturonic acid and much higher proportions of arabinose and galactose (Brat et al., 2002).

2.2. Amino acids and proteins

Regarding electrical treatments, it has been reported that PEF treatment halved the protein content in grape juice (Marsellés-Fontanet et al., 2013). Similarly, evidence suggests that microwave treatment could reduce the content of total amino-nitrogen in apple juices (Zhang et al., 2010a). During US treatment, protein concentration has been found to be significantly affected by processing time and US intensity; however, higher protein content in treated juices than in non-treated ones might be attributable to protein release due to cell disruption by sonication. Conversely, upon increasing the US intensity and exposure time (above 7 min at intensities higher than 226 W/cm^2), a decrease in protein content was observed. This reaction may occur when the rate of protein loss surpasses the extraction rate (Costa et al., 2013).

2.3. Vitamins

Fruits and vegetables are good sources of vitamin C (Zen et al., 2002), which is the main vitamin found and therefore the vitamin reviewed in this section.

2.3.1. Radiation treatment

Vitamin C is a light-sensitive vitamin in fruit juices and can be degraded by UV treatment. Authors have reported that ascorbic acid degradation occurred more rapidly at higher UV dosages and the reaction accelerated with increasing exposure times (Tikekar et al., 2011). Falguera et al., 2011 reported a slight decrease during UV experiments with treatments up to 100 min applying an incident energy of $3.88 \cdot 10^{-7}$ E/min. UV pulsed light has been reported to cause a minor reduction in vitamin C, between 0.85-12.31% at 31-644 J/pulse, and 0.5 Hz (Orlowska et al., 2012).

It has been stated that 5 kGy of ɔ-irradiation decreased the vitamin C percentage gradually to 62.5% in carrot-juice samples (Jo and Lee. 2012, Jo et al., 2012). A dose-dependent decrease in vitamin C content has also been reported in previous studies (Song et al., 2007, Jo et al., 2012).

2.3.2. Electric treatment

The effects of PEF processing on content of vitamin C have been reported extensively in literature. Scientific evidence indicates high vitamin C retention after PEF processing in orange juice and gazpacho (Elez-Martínez and Martín-Belloso. 2007), tomato juice (Nguyen and Mittal. 2007), and orange-carrot (Torregrosa et al., 2006), carrot (Akin and Evrendilek. 2009), and strawberry (Odriozola-Serrano et al., 2009b), apple juice (Evrendilek et al., 2000), and beverages containing fruit juice and milk (Salvia-Trujillo et al., 2011). However, other findings suggest that vitamin C retention is reduced after the PEF treatment (Bi et al., 2013, Oms-Oliu et al., 2009), although there is no consensus regarding the effect of electric-field strength on this reduction. Under similar PEF conditions, differences in vitamin C retention among PEF-treated juices could be due to their different pH, since more acidic conditions are known to stabilize vitamin C (Tannenbaum et al., 1985, Bi et al., 2013, Oms-Oliu et al., 2009). Several authors have compared the impact of PEF with the impact of thermal processing on vitamin C stability in different juices. Thus, thermal pasteurization is often found to be more detrimental than PEF pasteurization to vitamin C (Vervoort et al., 2011, Elez-Martínez et al., 2006, Elez-Martínez and Martín-Belloso. 2007, Yeom et al., 2000, Min et al., 2003, Zhang et al., 2010c, Odriozola-Serrano et al., 2008a, Odriozola-Serrano et al., 2008b, Cortés et al., 2008).

Regarding RFEF treatments, Geveke et al., 2007 processed orange juice on a pilot-plant scale at 15 and 20 kV/cm at frequencies of 21, 30, and 40 kHz, and at an outlet temperature of 65°C with a holding time of 2 s, finding no loss in ascorbic acid due to RFEF processing, probably due to the short treatment time and low temperature.

Several authors have asserted that the type of heating (ohmic or conventional) had no significant effect on vitamin C degradation (Leizerson and Shimoni. 2005a, Leizerson and Shimoni. 2005b, Lima et al., 1999, Tumpanuvatr and Jittanit. 2012). However, the vitamin C contents of ohmically heated juices were significantly lower than those of unheated juices. Similarly, Demirdöven and Baysal (2012) found minor differences between vitamin C contents of OH treated samples compared to conventional treatments. On the other hand, other authors have reported that the concentration of vitamin C in orange juice continuously ohmic-heated at 25-45 V/cm was significantly higher than in the conventionally heated juice (Lee et al., 2012, Vikram et al., 2005).

ACCEPTED MANUSCRIPT

2.3.3. Microwave heating (MH) treatment

According to Vikram et al., (2005), the degradation of vitamin C was highest during MH at 455W 180s due to uncontrolled temperature generated during processing compared to OH, infrared heating, and conventional heating. However, other authors reported that treatment at 900 W for 30 s - 10 min preserved vitamin C compared to conventional thermal heating (Igual et al., 2010b; Géczi, G et al., 2013).

2.3.4. Ultrasound (US) treatment

US processing of juices is reported to have minimal effects on the degradation of key quality parameters such as vitamin C in orange juice during storage at 10°C (Tiwari et al., 2009a, Tiwari et al., 2009b, Tiwari et al., 2009d). Positive effect of US on vitamin C retention was also found by (Cheng et al., 2007, Zenker et al., 2003, Bhat et al., 2001b, Zafra-Rojas et al., 2013, Abid et al., 2013). Some authors attribute this fact to the elimination of dissolved oxygen, which is essential for ascorbic acid degradation during cavitation, produced during sonication treatments (Bhat et al., 2001b, Adekunte et al., 2010a, Adekunte et al., 2010b, Knorr et al., 2004, Zafra-Rojas et al., 2013). However, the ascorbic acid content significantly decreased in juice processed by sonication when compared to control (Santhirasegaram et al., 2013), in agreement with other authors (Gómez-López et al., 2010, Gómez-López et al., 2005) and also with Adekunte et al., (2010b), who also reported that the decrease in ascorbic acid content is influenced by amplitude level and treatment time. The degradation of ascorbic acid could be explained by the formation of free radicals by sonochemical reaction, associated with oxidative processes (Hart and Henglein. 1985).

ACCEPTED MANUSCRIPT

2.3.5. *High hydrostatic pressure (HHP)*

Queiroz et al., (2010) reported that vitamin C content in cashew juice did not change significantly in all samples treated at 250 MPa. However, contents significantly fell in samples pressurized at 400 MPa for 7 min compared to control. Similarly, other authors reported that HHP did not cause any significant changes in vitamin C in cloudy apple juice at 500 MPa, 3 min, and 25°C (Kim et al., 2012).

In terms of vitamin C stability after processing, after 6 months of storage at 4°C ascorbic acid decreased by 39.41% in cloudy juices, and by 48.91% in clear juices (Cao et al., 2012) in strawberry juices treated at 600 MPa for 4 min, at 25°C. A high-pressure treatment of 500 MPa at 35°C for 5 min led to a better ascorbic acid retention during post-processing storage of orange juice at 0-15°C compared to conventional thermal pasteurization (80°C, 30 s) (Polydera et al., 2003).

2.3.6. Gas treatment

Oulé et al., (2013), and Fabroni et al., (2010) found that vitamin C was preserved in higher quantity when supercritical CO_2 treatment at 23-25 MPa, 36-40 °C was applied in comparison with pasteurized orange juice. However, this treatment proved detrimental for this compound (12% less) when compared to non treated juices (Fabroni et al., 2010).

Significant reductions in ascorbic vitamin C content (85.8%-96%) were observed at an ozone concentration of 7.8% w/w and a treatment time of 10 min (Tiwari et al., 2009a, Tiwari et al., 2009f) in tomato and strawberry juices. Similarly, orange juice decreases from 41.59 to 12.70

mg/100 mL were registered after 10 min of treatment time at a gas-þow rate of 0.0625 L/min, the ascorbic acid degradation-rate constant increasing exponentially with respect to ozone concentration (Tiwari et al., 2008b).

3. Effect of technological processing on phytochemical content of fruit juices

In this section, the effect of technological fruit-juice processing on phytochemical content of juices is examined. The phytochemicals considered include terpenoids, alkaloids, and polyphenols. Carotenoids, being a particular class of terpenoids together with polyphenols have received growing attention in recent years due to the numerous publications that reveal their benefits for human health (Fernández-García et al., 2012). Tables 1 and 2 present the results achieved during the last decade in terms of the effect of selected alternatives to conventional thermal treatments in fruit-juice processing on their polyphenol and carotenoids content respectively.

3.1. Polyphenols

3.1.1. Radiation treatment

Total phenols, flavonols, and flavonoids have shown enhancement on exposure to UV, significant at 60 min (Bhat,R. 2011a). Other authors found no variations in total phenolics with treatments of up to 100 min applying an incident energy of $3.88 \cdot 10^{-7}$ E/min (Falguera et al., 2011). UV radiation also reportedly exerts a negative influence on anthocyanins. Bakowska et al., 2003 found a strong negative influence of UV irradiation on the complex of cyanidin-3-glucoside with copigment compared to thermal treatment at 80°C.

The polyphenol content has been found not to be affected by HILP treatment at dosages of 7-28 J/cm^2 (Palgan et al., 2011a, Palgan et al., 2011b) nor by the combination of HILP at dosages of 5.1-4.0 J/cm^2 and PEF at two field strengths (24-34 kV/cm)(Caminiti et al., 2009). Conversely, Caminiti et al., (2012) reported a significant decrease in total phenolics when applying a combination of HILP at 3.3 J/cm^2 with manothermosonication at 400 kPa and 35°C.

It has been stated that ɔ-irradiation induces negligible or subtle losses of nutrients and sensory qualities in food compared to thermal processing as it does not substantially raise the temperature of food during processing (Wood and Bruhn. 2000). Accordingly, the total phenolics in processed sugarcane juice did not change significantly upon addition of preservatives plus gamma-radiation processing at 5 kGy (Mishra et al., 2011).

However, other authors have reported an increase in the total phenol contents at 3-5 kGy in carrot and kale juices (Song et al., 2006) as well as tamarind juice, in a dose-dependent manner (Lee et al., 2009, Lee et al., 2006). Similarly, other authors (Bhat et al., 2011b, Ayed, N. 1999) reported that the anthocyanin content in grape pomace increased with the irradiation dose, at an optimum at 6 kGy. This increase in measured content may be due to the extraction of bound pigments by the degradation of the cell wall. Conversely, Alighourchi et al., (2008) found a significant reduction in the total and individual anthocyanin content in pomegranate juice after irradiation at higher doses (3.5-10 kGy) and that irradiation effects on anthocyanin pigments depend upon the nature of anthocyanin; for example, diglycosides are relatively stable towards the irradiation dose compared to monoglycosides.

3.1.2. Electric treatment

Regarding the effect of PEF on the polyphenol content of fruit juices, Odriozola-Serrano et al., (2009b) reported that the maximum values of anthocyanins were reached by combining high frequencies and low pulse widths irrespective of the pulse polarity. The effect of electric-field strength was assessed by Bi et al., (2013), who concluded that the retention of total phenols increased with greater electric-field strength regardless pulse rise times, so that total phenols treated at higher electric-field strengths did not significantly differ from control. There is no consensus in the literature regarding the retention of polyphenols. Numerous results show no significant differences in total phenolic content between untreated and PEF-treated tomato juices (Odriozola-Serrano et al., 2009a, Odriozola-Serrano et al., 2009b), juice-soymilk beverage (Morales-de la Peña et al., 2010), apple juice (Schilling et al., 2007), and tomato juice (Odriozola-Serrano et al., 2009a, Odriozola-Serrano et al., 2008a) with pulses of 4-400 εs, at 1-35 kV/cm field strength. Similarly, Odriozola-Serrano et al., (2008b) found no significant differences in flavonol content between treated and non-treated strawberry juice but detected minor differences in the anthocyanin content, which proved higher in untreated samples. Likewise, after the scaling-up on an industrial scale of apple-juice production, PEF treatment at 650 V/cm, 23.2 ms did not significantly affect the concentration of native polyphenol compounds in the mash. Furthermore, the concentration of total native polyphenols in the juices increased by 8.8% due to PEF treatment of the mash when the samples were preserved from enzymatic oxidation (Turk et al., 2012b). In contrast to the above findings, evidence in grape-juice extraction also suggests that PEF application might have increased the polyphenol content in a regime of progressive pressure increase (from 0 to 1 bar in 1 h) at 400 V/cm as compared with juice produced in the regime of constant pressure (Grimi et al., 2009). A positive impact of PEF

 ACCEPTED MANUSCRIPT

on the extraction of polyphenols was also observed in juices after PEF treatment of apple juice (Grimi et al., 2011, Bhat et al., 2011b, Schilling et al., 2008) and grape juice (Puértolas et al., 2009, 2010). Likewise, same authors found that the concentration of anthocyanins and phenolic compounds during fermentation of red grapes was higher in the PEF-treated samples than in controls, this effect increasing with the electric-field strength until 5 kV/cm (Puértolas et al., 2010). Similarly, fewer polyphenol losses (18%) have been noted during PEF treatments at 32-35 kV/cm, 3-4 µs when compared to conventional heat treatments at 90-100°C for a holding time of 30 s to 1 min (32-42%) (Aguilar-Rosas et al., 2007, Zhang et al., 2010c). Additionally, Zhang et al., (2008) reported that the degradation rate constant of cyanidin-3-glucoside, which compares favorably to that for thermal treatment. By contrast, (Turk et al., 2010) found a decline in native polyphenol yield due to PEF treatment at 450 V/cm and 10 ms, representing 54% of the polyphenols for a large mash and 17% for a small mash compared to untreated samples. These authors attributed this decrease to greater oxidation of phenolic compounds in cells due to the electroporation of the inner-cell membrane and the adsorption of the oxidized products onto the mash. When apple mash was treated on a pilot-plant scale (1000 V/cm, 100 εs), a 17.8% loss was recorded (Turk et al., 2012a).

Regarding OH treatments, (Yildiz et al., 2009) found that the heating process increased the amount of phenolics, with no difference between ohmic and conventional heating. Both treatments reached 90°C and remained at this temperature for 0-12 min.

3.1.3. Microwave heating (MH) treatment

Research on apple puree showed that MH to 70-80°C maintained the polyphenol content after the treatment (Picouet et al., 2009). Similarly, De Ancos et al., (1999) found no significant change in total anthocyanin concentration. However, Zhang and Wen (2013), and Zhang et al., (2010b) found that microwave increased total polyphenol content in peach and apple juice by reducing polyphenol oxidases activity. Similar results were obtained by Slavov et al., 2013 in red beet juice.

3.1.4. Ultrasound (US) treatment

The application of US-assisted extraction has been reported to improve the extraction yield of bioactive compounds by between 30 and 35% compared to freshly squeezed juice (Santhirasegaram et al., 2013). This result agrees with the findings of other authors (Tiwari et al., 2010, Zafra-Rojas et al., 2013, Abid et al., 2013 and 2014, Bhat et al., 2011b), who found a significant increase in the total phenolic content in sonicated juice samples when compared to a control, this being due possibly to the greater disruption of cell walls, facilitating the release of bound phenolic contents.

The effect of US on anthocyanins was studied in strawberry juice by Tiwari et al., (2008a). These researchers detected a slight increase (1ï 2%) in the pelargonidin-3-glucoside content of the juice at lower amplitude levels and treatment times, possibly due to the extraction of bound anthocyanins from the suspended pulp.

Conversely, according to other authors (Fonteles et al., 2012), the polyphenol content of juice degraded by 30%. This degradation of anthocyanins might have been due to cavitation, which involves the formation, growth, and collapse of microscopic bubbles (Tiwari et al., 2009b).

3.1.5. High hydrostatic pressure (HHP) treatment

HHP treatments have been found to augment the total polyphenol content at 200-500 MPa, 2.5-25 min at room temperature (Chen et al., 2013, Queiroz et al., 2010, Kim et al., 2012). This could have resulted from plant-cell disruption caused by pressure, leading to higher extractability of these compounds.

HPP treatment at ambient temperature is reported to have minimal effects on the anthocyanin content of various fruits and vegetables (Tiwari et al., 2009b, Liu et al., 2013). Many researchers examine the retention of anthocyanins, including Corrales et al., (2008), who reported an insignificant reduction in cyanidin-3-glucoside in a model solution at processing conditions of 600 MPa, 20°C and 30 min. However, these authors reported a 25% loss at 600 MPa, 70°C for 30 min compared to a 5% loss at 70°C for 30 min, indicating that HHP accelerates anthocyanin reduction at elevated temperatures, which is in accordance to Engman et al., (2014), who reported that the combined effect of increasing temperature and pressure resulted in decreased amount of anthocyanins

Nevertheless, other authors reported a very specific trend regarding anthocyanin retention after the HHP treatment. At room temperature, their concentration decreased with the pressure level and processing time. However, at temperatures higher than ambient, the treatment time is not a relevant parameter, and the application of the high pressure slightly depresses the anthocyanin content. If the operating temperature exceeds 45°C and the pressure level is higher than 400 MPa, anthocyanin content is similar or higher than the value estimated for the fresh juice. These researchers attribute this result to the fact that in this particular range of processing conditions the high-pressure treatment alters mainly the mechanism of anthocyanin degradation by affecting the molecules involved in the reaction kinetics, such as enzymes (Ferrari et al., 2010).

The stability of anthocyanins under storage after HHP treatment was evaluated by Zabetakis et al., (2000), the lowest losses being recorded after treatment at 800 Mpa under refrigerated storage when compared to treatments at 200-600 Mpa and ambient storage. Other studies have demonstrated that after 6 months of storage at4°C, anthocyanins diminished by 7-30% and total polyphenols by 14-16 % in strawberry juices (Cao et al., 2012).

3.1.6. Gas treatment

The retention of total phenolics, flavonoids and anthocyanins was observed for supercritical CO_2 juices under mild conditions (8-13 MPa, 36 °C) (Fabroni et al., 2010, Gasperi at al., 2009, and Guo et al., 2011). However, when higher pressures were employed (23 MPa, 36°C), this treatment proved detrimental for these compounds (Fabroni et al., 2010). In another study conducted by Del Pozo-Insfran et al., 2006, no significant changes in total anthocyanin content were reported for SC-CO_2 processed muscadine grape juice compared to a 16% loss in thermally processed juice. Enhanced anthocyanin stability was also found in the processed juice during storage for 10 weeks at 4°C, its fortification being due perhaps to the prevention of oxidation by the removal of dissolved oxygen.

Ozone treatment is generally expected to cause the loss of antioxidant constituents, because of its strong oxidizing activity. During ozonation, at higher processing conditions (4.8% w/w ozone concentration for 10 min processing time) a fall of 99.1%, 96.6%, 99.8%, and 49.7% was reported for chlorogenic acid, caffeic acid, cinnamic acid, and the total phenol content, respectively (Torres et al., 2011). Similarly, according to Patil et al., (2010b), a processing time required to achieve 5-log reductions for *E. coli* under similar experimental conditions showed a 66.5%, 73.5% and 65.0% drop for chlorogenic acid, caffeic acid, and cinnamic acid, respectively. This is in accordance to further research by same authors, who also found a signiýcant reduction in polyphenols for longer ozonation times (Patil et al., 2010a), or higher ozone concentrations (Torlak et al., 2014). Moreover, the ozonation of anthocyanin-rich fruit juices such as strawberry and blackberry has been reported to cause significant decline in these bioactive compounds. A reduction of 98.2% in the pelargonidin-3-glucoside content of strawberry juice was reported at an ozone concentration of 7.8% w/w processed for 10 min (Tiwari et al., 2009a, Tiwari et al., 2009b, Tiwari et al., 2009c, Tiwari et al., 2009f). Similar reductions of >90% in the cyanidin-3-glucoside content of blackberry juice were reported under similar treatment conditions (Tiwari 2009c). Significant losses in the anthocyanin content were recorded during ozonation. During ozonation, cyanidin-3-O-glucoside was found to be more stable compared to delphinidin-3-O-glucoside and malvidin-3-O-glucoside. Similarly, a decrease of 99.1%, 96.6%, 99.8%, and 49.7% was observed for chlorogenic acid, caffeic acid, cinnamic acid, and total phenol content, respectively (Tiwari et al., 2009e). By contrast, mild conditions (22°C for 40 min with 2.8 mg/L ozone) proved to have no significant effect on polyphenol content (Torlak et al., 2014).

3.1.7. Flash-vacuum expansion (FVE) treatment

The FVE process allows the fast extraction of all phenolic compounds (hydroxycinnamic acids, flavonols, anthocyanins, catechins, and proanthocyanidins) and can be used to produce polyphenol-enriched grape juices (Morel-Salmi et al., 2006, Paranjpe et al., 2012, Anonymous 2007, Brat et al., 2002). Paranjpe et al., (2012) reported that lower pressures (in the flash chamber) and higher initial fruit temperatures promote the extraction of polyphenolics into the juice.

3.2. Carotenoids

3.2.1. Electrical treatment

While Vervoort et al., (2011) found that PEF at 23 kV/cm, 2 εs had no significant effect on the carotenoid profile of orange juice, other authors agree on an increase in total carotenoids on applying 25-35 kV/cm (Odriozola-Serrano et al., 2009a, Odriozola-Serrano et al., 2009b, Torregrosa et al., 2006, Cortés et al., 2006, Vervoort et al., 2011). Regarding individual carotenoids, Odriozola-Serrano et al., (2007, 2008a, 2008b), and Valverdú-Queralt et al., (2013) found higher lycopene concentrations in PEF-processed tomato juice than in the untreated. The increase ranged from 1.0% to 65% after applying different PEF treatments, the maximum lycopene relative content being when PEF treatment was applied at 35 kV/cm for 1000-1500 εs with bipolar pulses of 4-7 εs at 100-250 Hz. This increase was higher in the PEF-treated samples than in pasteurized samples at 90°C for 30 and 60 s. The increase in lycopene just after processing coincided with a depletion of phytoene and neurosporene contents compared to the untreated juice. Thus, PEF might stimulate the transformation of some carotenoids into lycopene (Odriozola-Serrano et al., 2007, Odriozola-Serrano et al., 2009a). Similarly, Oms-Oliu et al., (2009) found 14% more lycopene in watermelon juice with 7-εs bipolar pulses for 1050 εs at 35 kV/cm and frequencies ranging from 200 to 250 Hz. Odriozola-Serrano et al., (2007) also found that ϐ-carotene in treated tomato juice significantly augmented (31-38%), whereas ɔ-carotene content was depleted (3-6%) after PEF treatment. A plausible explanation for this is that ɔ-carotene may undergo cyclization to form six-membered rings at one end of the molecule, giving ϐ-carotene as a product.

3.2.2. Microwave heating (MH) treatment

Carotenoid degradation in orange juice was monitored during MH at different time/temperature conditions. Various carotenoids were identified and quantified by HPLC. The degradation rate of carotenoids was influenced by MH temperatures: at 60°C and 70°C for 10 min, violaxanthin and antheraxanthin were the most unstable compounds, while lutein and provitamin A carotenoids were more stable. At 85°C a decrease of about 50% was observed for almost all carotenoids after 1 min of MH (Fratianni et al., 2010). Microwave treatment has been demonstrated to induce the degradative loss of total carotenoid content, 475W for 45s provoking the greatest loss of the total carotenoid (57%) in papaya puree (De Ancos et al., 1999).

3.2.3. Ultrasound (US) treatment

Juice samples subjected to sonication showed significant rises in carotenoid content, registering great improvement in extractability of carotenoids (9%) when compared to the control (Santhirasegaram et al., 2013). Thus, carotenoids are still stable after 15 and 30 min of sonication. This may be explained by the inactivation of enzymes responsible for carotenoid degradation due to cavitation-induced shock waves and sonochemical reaction (Demirdöven and Baysal. 2009). Moreover, combined treatment of acid blanching and sonication proved higher increase in total carotenoids, lycopene and lutein than in only sonicated juices (Jabbar et al., 2014).

3.2.4. High hydrostatic pressure (HHP)

Liu et al., (2013) concluded that carotenoids resulted unaffected by HHP treatment at 200-400 MPa for 5-60 min, which is in accordance to other authors (Kim et al., 2001, Carreño et al., 2011). Moreover, Esteve et al., (2009) reported that the concentration of carotenoids is affected less by non-thermal treatments such as HHP than by conventional thermal treatments.

It has also been reported that high-pressure treatment at 300 MPa at 4 and 25°C, 10 min, total carotenoid and total lycopene contents significantly increased up to 62 and 56% respectively as compared with control in tomato juices (Hsu et al., 2008).

4. Effect of technological processing on physicochemical properties of fruit juices

Total soluble solids and pH; and cloudiness and turbidity are reviewed in tthis section.

4.1. Total soluble solids and pH

Radiation treatment has been reported to have no effect on the total soluble solids or pH, regardless of the type of treatment (Vanamala et al., 2007, Azhuvalappil et al., 2010, Falguera et al., 2011, Noci et al., 2008, Ibarz et al., 2005), and the same was found with the HILP treatment (Caminiti et al., 2009, Caminiti et al., 2011, Palgan et al., 2011b, Vanamala et al., 2007).

Similarly, electrical treatments exerted no effect with respect to pH or total soluble solids (Azhuvalappil et al., 2010, Zárate-Rodríguez et al., 2000). However, when the effect of OH treatments on the pH of the samples was studied, a drop in pH was found, attributed by Tolstoguzov. (1990) to the ionization that took place inside the pulp during the migration of ions from the positive anode to the negative cathode, which produced more hydrogen ion than hydroxyl ion. In contrast to this finding, other authors have reported that OH exerts no significant changes in pH or total soluble solids of juices (Yildiz et al., 2009).

The MH treatment has been reported to slightly increase the acidity of apple juice (Zhang et al., 2010a). This agrees with Igual et al., (2010a), who reported that jams processed with 900 W of power microwave exhibited significantly lower pH values.

Moreover, the literature shows that the sonication treatment and time had no effect on pH or total soluble solids in juices (Zafra-Rojas et al., 2013, Abid et al., 2013, Santhirasegaram et al., 2013, Bhat et al., 2011, Adekunte et al., 2010b). However, other authors found significant changes in pH after processing fruit-juice samples. With the processing of pineapple juice, pH fell as temperature rose to 40, 50, and 60°C and when the US treatment was pulsed instead of continuous. In contrast, when processing cranberry juice, this trend was reversed and pH rose when temperature was raised and pulsed treatments were applied (Bermúdez-Aguirre and Barbosa-Cánovas. 2012). The change of pH in the thermo-sonicated juices could be due to the formation of some chemical products in the treatment medium, such as nitrite, hydrogen peroxide, and nitrate, as shown by Supeno and Kruus (2000) when sonication was applied in aqueous media.

Other treatments such as HHP or gas treatments (SC-CO_2 and ozonation) were found not to prompt any change in pH of fruit juices nor total soluble solids (Hartyáni et al., 2013, Mert et al., 2013, Hartyáni et al., 2011, Fabroni et al., 2010, Choi and Nielsen. 2005, Chen et al., 2013).

Similarly, FVE treatment had no significant effect on grape juice pH, or total soluble solids (Paranjpe et al., 2012, Tiwari et al., 2008b). However, Brat et al., (2002) reported lower total soluble solids and higher pH in flash-vacuum-expanded passion fruit purees than those of reference juice. This is explained by a dilution of the inner juice from the aril by the rind.

4.2. Cloudiness and turbidity

After electrical treatments such as PEF, juices mechanically expressed from treated samples usually have less turbidity (Grimi et al., 2011, Grimi et al., 2007, Praporscic et al., 2007). Moreover, Zhu et al., (2013) reported that the diffusion juices obtained at lower temperatures of 60 and 30 °C from PEF treated chicory have lower turbidity than the conventional juice obtained at 80 °C. By contrast, it has been demonstrated that sonication treatment significantly increased the degree of cloudiness of apple juice (Abid et al., 2013, and 2014). The higher cloudiness value might be due to the high-pressure gradient by cavitation during the sonication treatment, causing colloidal disintegration plus the dispersion and breakdown of macromolecules to smaller ones, thereby making the juice properly homogenized and more consistent. Some studies indicate that US may reduce the molecular weight of pectin by breaking its linear molecule and thus producing a weaker network (Seshadri et al., 2003).

Other treatments such as HHP, have proved to increase cloudiness. Liu et al., (2013) reported that after HHP treatment, the cloudiness of juice increased with increase in pressure (200 to 600 MPa) compared to the control, but it did not change significantly with increase in treatment time (0 to 60 min) under the same pressure. Accordingly, Carreño et al., (2013) reported that HHP significantly reduced the transmittance of orange juices, leading to a more opaque juice, which may be due to greater stabilization of the juice cloud.

With regards to CO_2 treatment, an influence on cloudiness has been noted, density being not only preserved but even augmented (Fabroni et al., 2010). This phenomenon it attributable, as other authors have previously proposed, to the depressurization of the system, which homogenizes orange juice, rupturing particles in the juice colloid, thereby increasing cloudiness (Kincal et al.,

 ACCEPTED MANUSCRIPT

2006). On the contrary, other authors appreciated no significant differences between ozone-treated samples and their respective controls. However, ozone treatment preserved turbidity to a far higher degree than in thermally pasteurized juices (Choi and Nielsen. 2005).

5. Effect of technological processing on rheological properties of fruit juices

Radiation treatments such as UV have been reported to not have any significant effect on the rheological behaviour of the juice and to preserve similar quality attributes as the untreated juice (Manzocco et al., 2009, Shamsudin et al., 2013).

Similarly, no variations in PEF-treated apple mash were observed, having no effect on the flow properties of the apple juices relative to their controls (Schilling et al., 2007). However, Bi et al., (2013) found less apparent viscosity and a lower consistency index of apple juice as well as a higher flow-behavior index on increasing the electric-field strength. This author attributes these findings to the breakdown of a colloidal suspension, which may be caused by the depolymerization of macromolecules present in the juice suspension (Tiwari et al., 2008d). By contrast, Aguiló-Aguayo et al., (2010a) reported that PEF treatment led watermelon juices to have a higher viscosity than in the unprocessed products. It was suggested that the strong reduction of pectin methylesterase activity achieved by PEF treatments may disrupt the chain reaction of pectin methylesterase and polygalacturonase to avoid losses in the viscosity of the processed juices, and more soluble pectin might be leached from cell walls, resulting in a product with higher viscosity. The difference between these results might be caused by different juice preparations and juice varieties, resulting in varying pectin contents and components. During OH treatments, it has been reported that consistency coefficients significantly decreased while temperatures increased (Icier and Tavman. 2006)(Yildiz et al., 2009). Through OH treatments, during the heating-up period of juices to 90°C, the consistency coefficient fell compared to that of the fresh juice, whereas no significant change was detected in this value during a holding period at 90°C. A similar trend was observed for flow-behavior indexes. Same trend was found during conventional heating, and therefore it was concluded that, in addition to thermal effects, ohmic heating had no electrical effect on rheological characteristics (Yildiz et al., 2009).

Regarding the effect of MH on fruit juices, the MH reportedly reduced the degree of serum separation on tomato juices when compared to the conventional hot break treatment, being more pronounced when the tomatoes were quartered instead of crushed (Kaur et al., 2007). Similarly, MH has been reported to increase the consistency of jam samples (Igual et al., 2010a).US processing reportedly diminishes juice viscosity by 75% of the initial value for non-sonicated juice (Costa et al., 2013), so that the higher the US intensity and processing time, the lower the viscosity. Seshadri et al., (2003) explain that the rheological properties of pectin that was treated with ultrasound can be negatively influenced. As sonication time and intensity is increased, the gel strength is reduced and time of gelation is increased. However, viscosity has been reported to increase in juices after sonication, which has been attributed to the reduction of the average particle size compared to the untreated juice (Wu et al., 2008), and also to the extraction of bound form of macromolecules that increase their concentration in the colloidal system and make the juice more viscous (Suárez-Jacobo et al., 2011).. High hydrostatic pressure treatments have shown some effects on viscosity of fruit juices. Higher apparent viscosity values were determined for highly pressurized orange juices compared to thermally treated ones immediately after processing. Suspended pulp decreased significantly after the application of pressure and was more pronounced after HPH treatment. HPH treatment is known to reduce

 ACCEPTED MANUSCRIPT

particle size, converting part of the sedimentable pulp into colloidal pulp (Polydera et al., 2003). However, other authors found that the viscosity of cloudy and clear juices showed no significant alteration in the shear rate range between 4 and 63 s^{-1}, suggesting that the juices followed the Newtonian flow behavior, and the flow behavior was well retained regardless of the storage temperature and time. However, the viscosity of cloudy juices decreased by 32-67%, corresponding to 1-6 months of storage at 4 °C. The result was in agreement with an earlier study. Hsu et al., (2008) found that the viscosity of HHP-treated tomato juice (400 MPa/15 or 30 min/20 °C) gradually decreased by extending storage time at 4 °C. Loss of the viscosity in cloudy juices was possibly attributed to the precipitation of pulps and degradation of pectin. It has been reported that pectin can be degraded through enzymatic and non-enzymatic degradation mechanisms (Sila et al., 2009). Likewise, the effect of moderate temperature (42.4ï 62.4 °C) at pressures between 200 and 300 MPa in the rate of viscosity reduction of pectin solutions has been studied. It has been found that it increased with temperature with a maximum of 0.0960 Pa^{-1} s^{-2} at 62.4 °C and 300 MPa which represented a 2.6-fold increase in rate of viscosity reduction relative to conditions of 45 °C and 0.1 MPa (Tomlin et al., 2014). Regarding the effect of supercritical CO_2 in juices, Zhou et al., (2009) reported that it did not alter the Newtonian flow behavior of carrot juice, but it caused a significant increase in juice viscosity. Additionally, significant changes were observed in consistency and flow-behavior indices of apple juice after ozonation. The consistency index decreased as a function of ozone concentration (Torres et al., 2011). A decline in the apparent viscosity value and a rise during ozonation result from the breakdown of a colloidal suspension which may be caused by the depolymerization of macromolecules present in the juice suspension (Tiwari et al., 2008d).

Regarding FVE treatments, the consistency and viscosity of the puree from treated samples was far higher than that of the reference puree and also the steam-heated puree, even with the reincorporation of aromatic liquors recovered during the treatment. The high viscosity is attributable mainly to its insoluble destarched alcohol content (Brat et al., 2002).

6. Effect of technological processing on organoleptic properties of fruit juices

In this section color, and aroma and flavor parameters are reviewed.

6.1. Color

6.1.1. Radiation treatment

Color values are usually monitored by *L, a, b* color space scales. Most popular color scales are Hunter *L, a, b* and CIE *L*, a*, b**; while similar in organization, a color will have different numerical values. In both of them the parameter *L* expresses whiteness or brightness/darkness, *a* representing the variation between red and green and *b* representing the variation between yellow and blue (Tiwari et al., 2009b). The total color difference (TCD or φ*E*) indicates the magnitude of color change after treatment. Differences in perceivable color can be analytically classified as not noticeable (0-0.5), slightly noticeable (0.5-1.5), noticeable (1.5-3.0), well visible (3.0-6.0) and great (6.0ï 12.0) (Clydesdale. 1978, Cserhalmi et al., 2006). In UV-radiated apple juices, L has been reported to increase in samples of Golden, Starking, and Fuji apple varieties; and Red Globe and Emperor grapes (Ibarz et al., 2005, Falguera et al., 2011 and 2013, Manzocco et al., 2009). However, this measurement is influenced by the fruit variety, normally fruit juices with high initial brightness, such as juice from King David apples, have kept its *L* value almost invariable, and fruits with high intial concentration of pigments experimented a greater variation.

The parameter *a* has been reported to decrease during irradiation in the samples from Golden, Starking, and Fuji, and also Red Globe grapes signifying that the juices became less red (Falguera et al., 2011, Ibarz et al., 2005, Falguera et al., 2013). Similarly, parameter *b* reportedly fluctuates greatly according to the variety employed, its value decreasing in the samples from Golden (which had the highest initial one), slightly increasing in the samples from Starking and Fuji, and remaining almost constant in the juice from King David, which had the lowest initial value (Falguera et al., 2011). Other authors have found a decline in this parameter in apple and lemon juices (Ibarz et al., 2005), in agreement with Guerrero-Beltrán and Barbosa-Cánovas. (2005) and Falguera et al., (2011 and 2013), who reported photodestruction of pigments in apple and grape juices. On the contrary, Caminiti et al, (2012) did not find significant differences between any of the color parameters studied.

HIPL treatment has revealed a slightly noticeable TCD (Caminiti et al., 2011) difference apple juice, regardless of the exposure time. To the contrary, further research revealed no significant differences among HIPL-treated samples and controls (Caminiti et al., 2011 and 2012). However, the application of manothermosonication as a second hurdle after HILP caused an increase in *L* and *b* parameters, while *a* remained insignificant (Caminiti et al., 2012).

6.1.2. Electrical treatment

Juice color has not been found to be adversely affected by PEF (Schilling et al., 2008). Higher φE, *L,* and *b* values have been reported in apple juice after PEF treatments, revealed as brighter color and more yellowness juice visible to the naked eye. It has been reported that color change was closely related to the enzymatic activity, such as polyphenoloxidase and peroxidase, which catalyzes the oxidation of phenolic compounds and causes enzymatic browning. Thus, the maintenance of apple-juice color might be due to the inactivation of these enzymes by PEF (Bi et al., 2013). Azhuvalappil et al., (2010) attributed the greater luminosity in treated cloudy apple juice to partial precipitation of insoluble suspended particles.

In terms of treatment combinations, PEF/HILP combinations affected the *L* and *b* color attributes with respect to the untreated control, although all combinations caused ñslightly noticeableò color changes (Caminiti et al., 2011).

However, Walkling-Ribeiro et al., (2008a, 2008b) found no significant difference in color between an untreated reconstituted apple juice and the product processed by UV/PEF combined treatments, while thermal processing (94°C for 26 s) caused a significant change in all color attributes. In a study on fresh apple juice, Noci et al., (2008) found that batch UV and PEF combinations also had less adverse effects on juice color than did heat pasteurization.

The *L* value of orange juice exposed to ohmic and conventionally heated juices did not signiýcantly differ from the control. Minor changes in *a* and *b* values were appreciated after both heating treatments. However, *a* and *b* color values of continuous ohmic-heating-treated samples were much closer to that of control than were the conventionally heated counterparts (Lee et al., 2012). In other studies, the color of ohmically heated juices proved insignificantly different from those of conventionally heated specimens; however differences with respect to control were found by a sensory panel (Tumpanuvatr and Jittanit. 2012). Ohmic heating also reportedly caused less browning during holding time than did conventional heating (Yildiz et al., 2009).

6.1.3. Microwave heating (MH) treatment

Research has indicated that microwave processing provokes lower degradation of color compared to infrared and ohmic heating (Vikram et al., 2005). Similarly, Yousefi et al., (2012) reported that all color parameters decreased with time; however, color degradation was more notable in conventional heating compared to the MH method. Nevertheless, microwave processing affected the color parameters *b* and *L* compared to non-treated samples (Stinco et al., 2013). By contrast, Cendres et al., (2011) produced brightly colored juices with MH, as this method may inactivate endogenous enzymes such as polyphenol oxidase prior to fruit grinding (Walkling-Ribeiro et al., 2008b).

6.1.4. Ultrasound (US) treatment

High-intensity US might release intracellular contents, which may affect the product color. The results have shown that sonication treatment significantly changes color between treated and non-treated juice samples. The sample treated for longer times registered the lowest *L* value, probably due to the release of intracellular compounds that slightly darkened the juice. On the other hand, *a* and *b* values rose, this being indicative of the release of red and yellow pigments, respectively (Abid et al., 2013, Costa et al., 2013). The results agree with the observations of sonicated kasturi lime juice (Bhat et al., 2011b); and Bermúdez-Aguirre and Barbosa-Cánovas (2012), who also found significant color differences between treated and non-treated samples. The color changes in fruit juice might be attributed to the cavitation during sonication (Tiwari et al., 2008a). However, shifts in apple-juice color after sonication could not be easily judged with the naked eye (Abid et al., 2013). In contrast, it has also been stated that US processing has no effect on color (Fonteles et al., 2012).

 ACCEPTED MANUSCRIPT

Manothermosonication applied as a second hurdle following UV and HILP treatment darkened the product. This was reflected in significantly lower *L* value and *a* values, indicating that the juice processed by the selected combinations was less bright and less red than was control. Also, a lowering of the *b* value suggested a trend towards a bluish color. Color measurements performed on the juice after processing by the first hurdle showed only that the product did not significantly differ from the untreated sample, regardless of the nature of the hurdle (UV or HILP). This result suggests that the manothermosonication treatment was responsible for the color changes observed in the product (Caminiti et al., 2011).

6.1.5. High hydrostatic pressure (HHP)

Effects of HHP in pomegranate juices have been assessed. Compared with the freshly squeezed juice, the *L* value of the HHP-treated juice slightly declined, while the high-temperature short-time pasteurized juice exhibited a significant rise in value, indicating greater brightness. The *a* values did not change after treatment, indicating no significant influence in terms of redness. The *b* value rose significantly, indicating that the blueness had faded and the yellowness had intensified. The φ*E* value was less than 1.5, indicative of slightly noticeable changes, while changes after high-temperature short-time pasteurization were noticeable. This implies that the effect of the HHP treatment on the pigments, such as chlorophylls, lycopenes, and anthocyanins, was weaker than that of high-temperature short-time pasteurization (Chen et al., 2013). By contrast, when the HPP treatment was applied to orange juice, the L value increased while the *a* value decreased and the *b* value was higher compared to the untreated sample (Hartyáni et al., 2011). This might be due to the different nature of the color pigments present in different fruit juices.

 ACCEPTED MANUSCRIPT

On examining the φE values, (Hartyáni et al., 2013) found only slightly noticeable differences in comparison to the control samples. The *L* value followed a rising trend with increasing pressure.

6.1.6. Gas treatment

With regard to color parameters, the *L*, *a*, and *b* values decreased after CO_2 treatment. However, these changes were not pronounced enough to significantly alter the characteristic color of the juice (Fabroni et al., 2010).

Regarding ozonation, Sung et al., (2014) reported that treatment at temperatures of 25-55°C did not significantly alter color parameters in apple juice samples. In contrast, apple-juice samples were observed to be lighter in color, i.e. higher *L* and *b* values, whereas *a* values of juice samples were found to decline with longer processing times and higher ozone concentrations (Torres et al., 2011, Patil et al., 2010a). However, ozonated strawberry juice samples were observed to be lighter in color, i.e. increased *L* value, whereas *a* and b^* values were found to fall with rising ozone concentrations and longer treatment times (Tiwari et al., 2009f); the same trend was followed by blackberry juice (Tiwari et al., 2009c). It has been reported that the chromophore of conjugated double bonds for anthocyanins or carotenoids, which are responsible for berry-juice color, may be degraded (Tiwari et al., 2009c). In orange juice a clear increase in lightness value (*L*) was discerned with an increased gas flow rate, ozone concentration, and treatment time. Conversely, *a* and *b* values decreased (Tiwari et al., 2008c). In further studies in orange juice, *L, a* and *b* values rose with respect to the ozone concentration (% w/w) at each gas-þow rate (Tiwari et al., 2008b).

6.1.7. Flash-vacuum expansion (FVE) treatment

 ACCEPTED MANUSCRIPT

Vacuum-expanded passion-fruit purees exhibited higher *a* values and lower *L* and *b* values than did the reference juice, which had a red-purple tone. By contrast, the reference juice was orangish-yellow due to carotenoids. This difference might be owed to the fact that the mesocarp containing most of anthocyanins is not disintegrated by the pulping step, while the FVE treatment may have loosen the tissue cohesion by creating microchannels, thus separating cells at their cell-wall level and facilitating extraction of color (Brat et al., 2001).

6.2. Aroma and flavor

6.2.1. Radiation treatment

Sensory evaluation has shown that samples treated with radiation dosages up to 10.62 J/cm^2 were comparable to control in terms of acceptability, though higher dosages adversely affected flavor (Caminiti et al., 2012). However, other authors reported that dosages of 34 J/cm^2 did not significantly alter the concentration of volatiles immediately after processing, although pronounced volatile differences between treatments were observed after 4 weeks at 4 °C . UV+PEF and HILP+PEF combinations did not alter either the odor or the flavor of the juice (Caminiti et al., 2011).

*6.2.2. Electric treatment*Odriozola-Serrano et al., (2013) have reviewed the effect off PEF on quality of fruit juices. Regarding aroma, authos agree on that this treatment helped to keep better flavour quality than thermal treatments since greater retentions of aroma compounds after processing were found compared to the thermally-treated and fresh juices (Aguiló-Aguayo et al., 2009, 2010b, 2010c, 2013, Aguilar-Rosas et al., 2007). After PEF treatment, volatile aroma components of orange juice, namely ethyl butyrate, linalool, decanal and valencene are not significantly lost. In the case of lemon juice, no marked decrease was detected in the amount of neral and geranial, character impact compounds. Meanwhile, the concentration of known off-flavor compounds (Ŭ-terpineol and terpinen-4-ol) remained constant (Cserhalmi et al., 2006). Similarly, nootkatone, a key aroma compound in grapefruit, did not significantly change (Cserhalmi et al., 2006). These observations agree with those of Aguilar-Rosas et al., (2007) and Yeom et al., (2000), who reported that volatile chemical compounds responsible for fruit-juice flavor are retained at a higher ratio in comparison to high-temperature short-time pasteurization with PEF-treated samples. Moreover, Valappil et al., (2009) reported that PEF treatment did not significantly affect the concentration of volatiles immediately after processing, although pronounced volatile differences were observed after 4 weeks at 4°C storage between trated and non-treated samples.

Ohmic-heated orange juice maintained higher amounts of the five representative flavor compounds than did heat-pasteurized juice. Moreover, sensory-evaluation tests revealed no difference between fresh and ohmic-heated orange juice (Leizerson and Shimoni. 2005a).

6.2.3. Ultrasound (US) treatment

Results for the aromatic profile of juices has shown that, compared to untreated samples of juices and nectars, ultrasonic treatment prompts the formation of new compounds or the disappearance of compounds that were present in the untreated samples, this being influenced by US amplitude level, sonication time, and temperature (Ġimunek et al., 2013). Similarly, Lee et al., (2013), applied sonication in combination with heat and low pressure. These authors found that right after the treatments, the concentrations of the key aroma compounds in the sonicated samples were higher than that in pasteurised samples, and were 1.2ï 29.5% lower than those in control. Combinations of manothermosonication, UV, and HIPL have been shown to adversely affect aroma and flavor attributes (Caminiti et al., 2011). By contrast, in terms of odor, flavor, and overall acceptability, no significant differences were detected by panelists between high-temperature short-time pasteurization (94°C for 26 s) and batch thermosonication at 55°C for 10 min followed by continuous PEF at a field strength of 40 kV/cm for 150 ε s (Walkling-Ribeiro et al., 2009).

6.2.4. High hydrostatic pressure (HHP)

The results of aroma analysis indicate that the quantity of ethyl-esters did not decrease in orange juice, except for beta-mircene, which slightly diminished after HHP treatment. A similar trend was observed for grapefruit juice, in which only ethyl octanoate decreased, while tangerine juice preserved all its aroma compounds (Hartyáni et al., 2011). In another study, concentrations of limonene, Ŭ-terpineol, and carvone were measured after HHP treatment. Pressure, temperature, and treatment time were found to be critical factors influencing changes in concentrations. Both pressure and temperature could cause limonene degradation, resulting in significant increases of Ŭ-terpineol and carvone concentrations (Pan et al., 2011).

Electronic noses have been used to predict aroma changes in treated apple and orange juices. Neither the pressure application nor the different pressure levels appeared to be relevant, as no significant differences were found in the separation of treated samples and controls applying a statistic supervised LDA method. By contrast, the electronic nose was able to differentiate clearly other parameters such as temperature and storage time regarding aroma changes (Hartyáni et al., 2013). Similarly, Laboissière et al., (2007) reported no significant changes in compounds

 ACCEPTED MANUSCRIPT

responsible for the yellow passion fruit juice aroma and flavor, when the data were analyzed through QDA and PCA.

7. Conclusion

The effects of alternatives to conventional heat treatments on nutritional, physicochemical, rheological, and organoleptic parameters in fruit-juice processing, are reviewed in this paper. The literature reveals that research is still underway, and many aspects remain to be fully studied and understood. In general, temperature during processing and storage is an important factor affecting the quality of the processed product. However, not only temperature but other factors are involved in quality losses. Although alternatives to heat treatments seem to be less detrimental than the thermal treatment, there are many parameters and conditions that influence the yield as well as the nature of the juice itself, making it difficult to compare different studies. There is also a lack of standardization in operating conditions, and consequently ambiguity arises within the literature, as these control conditions may not be reported in detail or are reported differently. Fundamental understanding of these phenomena is essential for optimum process design to ensure high-standard products. Additionally, future research should focus on understanding the mechanisms underlying the changes in the overall quality of fruit juices and should also delve into scaled-up processes, process design, and optimization. This investigation is needed in detail to maximize the potential of alternative non-thermal technologies in fruit-juice processing while maintaining maximum-quality fruit-juice attributes.

7. Acknowledgments

This work was supported by the project AGL2011-29857-C03-02 (Spanish Ministry of Science and Innovation), as well as by P09-CTS-4564, P10-FQM-6563 and P11-CTS-7625 (Andalusian Regional Government Council of Innovation and Science) projects. The authors are also grateful for the scholarship FPU AP2010-2793.

 ACCEPTED MANUSCRIPT

References

Anonymous. Improving grape juice yield and quality using flash vacuum expansion. (2007) *2007 ASABE Annual International Meeting, Technical Papers.* **12 BOOK**.

Abid, M., Jabbar, S., Hu, B., Hashim, M. M., Wu, T., Lei, S., Khan, M. A., andZeng, X. (2014a). Thermosonication as a potential quality enhancement technique of apple juice. *Ultrason Sonochem.* **21**: 984-990.

Abid, M., Jabbar, S., Wu, T., Hashim, M. M., Hu, B., Lei, S., andZeng, X. (2014b). Sonication enhances polyphenolic compounds, sugars, carotenoids and mineral elements of apple juice. *Ultrason Sonochem.* **21**: 93-97.

Abid, M., Jabbar, S., Wu, T., Hashim, M. M., Hu, B., Lei, S., Zhang, X., and Zeng, X. (2013). Effect of ultrasound on different quality parameters of apple juice. *Ultrason Sonochem.* **20**: 1182-1187.

Adekunte, A., Tiwari, B. K., Scannell, A., Cullen, P. J., and O'Donnell, C. (2010a). Modelling of yeast inactivation in sonicated tomato juice. *Int J Food Microbiol.* **137**: 116-120.

Adekunte, A. O., Tiwari, B. K., Cullen, P. J., Scannell, A. G. M., and Oʹ Donnell, C. P. (2010b). Effect of sonication on colour, ascorbic acid and yeast inactivation in tomato juice. *Food Chem.* **122**: 500-507.

 ACCEPTED MANUSCRIPT

Aguilar-Rosas, S. F., Ballinas-Casarrubias, M. L., Nevarez-Moorillon, G. V., Martin-Belloso, O., and Ortega-Rivas, E. (2007). Thermal and pulsed electric fields pasteurization of apple juice: Effects on physicochemical properties and flavour compounds. *J Food Eng.* **83**: 41-46.

Aguiló-Aguayo, I., Soliva-Fortuny, R., and Martín-Belloso, O. (2010a). Optimizing critical high-intensity pulsed electric fields treatments for reducing pectolytic activity and viscosity changes in watermelon juice. *European Food Research and Technology.* **231**: 509-517.

Aguiló-Aguayo, I., Montero-Calderón, M., Soliva-Fortuny, R., andMartín-Belloso, O. (2010b). Changes on flavor compounds throughout cold storage of watermelon juice processed by high-intensity pulsed electric fields or heat. *J Food Eng.* **100**: 43-49.

Aguiló-Aguayo, I., Oms-Oliu, G., Soliva-Fortuny, R., andMartín-Belloso, O. (2009). Flavour retention and related enzyme activities during storage of strawberry juices processed by high-intensity pulsed electric fields or heat. *Food Chem.* **116**: 59-65.

Aguiló-Aguayo, I., Soliva-Fortuny, R., andMartín-Belloso, O. (2010c). Volatile compounds and changes in flavour-related enzymes during cold storage of high-intensity pulsed electric fieldand heat-processed tomato juices. *J Sci Food Agric.* **90**: 1597-1604.

Akin, E. and Evrendilek, G. A. (2009). Effect of pulsed electric fields on physical, chemical, and microbiological properties of formulated carrot juice. *Food Sci Technol Int.* **15**: 275-282.

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

Ayed, N., Yu, H., andLacroix, M. (1999). Improvement of anthocyanin yield and shelf-life extension of grape pomace by gamma irradiation. *Food Research International*. **32**: 539-543.

Azhuvalappil, Z., Fan, X., Geveke, D. J., and Zhang, H. Q. (2010). Thermal and nonthermal processing of apple cider: Storage quality under equivalent process conditions. *J Food Qual.* **33**: 612-631.

Bakowska, A., Kucharska, A. Z., and OszmiaŒski, J. (2003). The effects of heating, UV irradiation, and storage on stability of the anthocyanin-polyphenol copigment complex. *Food Chemistry.* **81**: 349-355.

Bermúdez-Aguirre, D. and Barbosa-Cánovas, G. V. (2012). Inactivation of Saccharomyces cerevisiae in pineapple, grape and cranberry juices under pulsed and continuous thermo-sonication treatments. *J Food Eng.* **108**: 383-392.

Bhat, R., Ameran, S. B., Voon, H. C., Karim, A. A., and Tze, L. M. (2011a). Quality attributes of starfruit (*Averrhoa carambola* L.) juice treated with ultraviolet radiation. *Food Chem.* **127**: 641-644.

Bhat, R., Kamaruddin, N. S. B. C., Min-Tze, L., and Karim, A. A. (2011b). Sonication improves kasturi lime (*Citrus microcarpa*) juice quality. *Ultrason Sonochem.* **18**: 1295-1300.

Bi, X., Liu, F., Rao, L., Li, J., Liu, B., Liao, X., and Wu, J. (2013). Effects of electric field strength and pulse rise time on physicochemical and sensory properties of apple juice by pulsed electric field. *Innovative Food Science and Emerging Technologies.* **17**: 85-92.

Brat, P., Olle, D., Reynes, M., Alter, P., Brillouet, J., and Cogat, P. O. (2002). Preparation of tropical fruit purees by flash vacuum-expansion. *International symposium on tropical and subtropical fruits.*: 535-541.

Caminiti, I. M., Noci, F., Morgan, D. J., Cronin, D. A., and Lyng, J. G. (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**: 442-448.

Caminiti, I. M., Noci, F., Muñoz, A., Whyte, P., Morgan, D. J., Cronin, D. A., and Lyng, J. G. (2011). Impact of selected combinations of non-thermal processing technologies on the quality of an apple and cranberry juice blend. *Food Chem.* **124**: 1387-1392.

Caminiti, I. M., Palgan, I., Muñoz, A., Noci, F., Whyte, P., Morgan, D. J., Cronin, D. A., and Lyng, J. G. (2012). The Effect of Ultraviolet Light on Microbial Inactivation and Quality Attributes of Apple Juice. *Food and Bioprocess Technology.* **5**: 680-686.

Caminiti, I. M., Palgan, I., Noci, F., Muñoz, A., Whyte, P., Cronin, D. A., Morgan, D. J., and Lyng, J. G. (2011). 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. *Innovative Food Science and Emerging Technologies.* **12**: 118-123.

Caminiti, I. M., Palgan, I., Noci, F., Muñoz, A., Whyte, P., Cronin, D. A., Morgan, D. J., and Lyng, J. G. (2009). Evaluation of *Escherichia coli* inactivation and quality attributes in apple juice subjected to Pulsed electric fields (PEF) in combination with high intensity light pulses

(HILP). *5th International Technical Symposium on Food Processing, Monitoring Technology in Bioprocesses and Food Quality Management.*: 396-406.

Cao, X., Bi, X., Huang, W., Wu, J., Hu, X., and Liao, X. (2012). Changes of quality of high hydrostatic pressure processed cloudy and clear strawberry juices during storage. *Innovative Food Science & Emerging Technologies.* **16**: 181-190.

Carreño, J. M., Gurrea, M. C., Sampedro, F., and Carbonell, J. V. (2011). Effect of high hydrostatic pressure and high-pressure homogenisation on *Lactobacillus plantarum* inactivation kinetics and quality parameters of mandarin juice. *European Food Research and Technology.* **232**: 265-274.

Cendres, A., Chemat, F., Maingonnat, J., and Renard, C. M. G. C. (2011). An innovative process for extraction of fruit juice using microwave heating. *LWT - Food Science and Technology.* **44**: 1035-1041.

Cendres, A., Chemat, F., Page, D., Le Bourvellec, C., Markowski, J., Zbrzezniak, M., Renard, C. M. G. C., and Plocharski, W. (2012). Comparison between microwave hydrodiffusion and pressing for plum juice extraction. *LWT - Food Science and Technology.* **49**: 229-237.

Chen, D., Xi, H., Guo, X., Qin, Z., Pang, X., Hu, X., Liao, X., and Wu, J. (2013). Comparative study of quality of cloudy pomegranate juice treated by high hydrostatic pressure and high temperature short time. *Innovative Food Science and Emerging Technologies.*

Cheng, L. H., Soh, C. Y., Liew, S. C., and Teh, F. F. (2007). Effects of sonication and carbonation on guava juice quality. *Food Chem.* **104**: 1396-1401.

 ACCEPTED MANUSCRIPT

Choi, L. H. and Nielsen, S. S. (2005). The effects of thermal and nonthermal processing methods on apple cider quality and consumer acceptability. *J Food Qual.* **28**: 13-29.

Clydesdale, F. M. (1978). Colorimetry-methodology and applications. *CRC Crit Rev Food Sci Nutr.* **10**: 243-301.

Corrales, M., Butz, P., and Tauscher, B. (2008). Anthocyanin condensation reactions under high hydrostatic pressure. *Food Chemistry.* **110**: 627-635.

Cortés, C., Esteve, M. J., and Frígola, A. (2008). Effect of refrigerated storage on ascorbic acid content of orange juice treated by pulsed electric fields and thermal pasteurization. *European Food Research and Technology.* **227**: 629-635.

Cortés, C., Esteve, M. J., Rodrigo, D., Torregrosa, F., and Frígola, A. (2006). Changes of colour and carotenoids contents during high intensity pulsed electric field treatment in orange juices. *Food and Chemical Toxicology.* **44**: 1932-1939.

Costa, M. G. M., Fonteles, T. V., de Jesus, A. L. T., Almeida, F. D. L., de Miranda, M. R. A., Fernandes, F. A. N., and Rodrigues, S. (2013). High-Intensity Ultrasound Processing of Pineapple Juice. *Food and Bioprocess Technology.* **6**: 997-1006.

Cserhalmi, Z., Sass-Kiss, Á., Tóth-Markus, M., and Lechner, N. (2006). Study of pulsed electric field treated citrus juices. *Innovative Food Science & Emerging Technologies.* **7**: 49-54.

De Ancos, B., Cano, M. P., Hernandez, A., and Monreal, M. (1999). Effects of microwave heating on pigment composition and colour of fruit purees. *J Sci Food Agric.* **79**: 663-670.

Del Pozo-Insfran, D., Balaban, M. O., and Talcott, S. T. (2006). Enhancing the retention of phytochemicals and organoleptic attributes in muscadine grape juice through a combined approach between dense phase CO_2 processing and copigmentation. *Journal of Agricultural and Food Chemistry.* **54**: 6705-6712.

Demirdöven, A. and Baysal, T. (2012). Optimization of ohmic heating applications for pectin methylesterase inactivation in orange juice. *Journal of Food Science and Technology.*: 1-10.

Demirdöven, A. and Baysal, T. (2009). The use of ultrasound and combined technologies in food preservation. *Food Rev Int.* **25**: 1-11.

Elez-Martínez, P. and Martín-Belloso, O. (2007). Effects of high intensity pulsed electric field processing conditions on vitamin C and antioxidant capacity of orange juice and gazpacho, a cold vegetable soup. *Food Chem.* **102**: 201-209.

Elez-Martínez, P., Soliva-Fortuny, R. C., and Martín-Belloso, O. (2006). Comparative study on shelf life of orange juice processed by high intensity pulsed electric fields or heat treatment. *European Food Research and Technology.* **222**: 321-329.

Elsinghorst, A. and Tikekar, R. V. (2014). Generation of oxidative species from ultraviolet light induced photolysis of fructose. *Food Chem.* **154**: 276-281.

Engmann, F. N., Ma, Y., Zhang, H., Yu, L., andDeng, N. (2014). 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.*

Esteve, M. I., Barba, F. J., Palop, S., andFrígola, A. (2009). The effects of non-thermal processing on carotenoids in orange juice. *Czech Journal of Food Sciences.* **27**: S304-S306.

Evrendilek, G. A., Jin, Z. T., Ruhlman, K. T., Qiu, X., Zhang, Q. H., and Richter, E. R. (2000). Microbial safety and shelf-life of apple juice and cider processed by bench and pilot scale PEF systems. *Innovative Food Science and Emerging Technologies.* **1**: 77-86.

Fabroni, S., Amenta, M., Timpanaro, N., and Rapisarda, P. (2010). Supercritical carbon dioxide-treated blood orange juice as a new product in the fresh fruit juice market. *Innovative Food Science and Emerging Technologies.* **11**: 477-484.

Falguera, V., Garza, S., Pagán, J., Garvín, A., andIbarz, A. (2013). Effect of UV-Vis Irradiation on Enzymatic Activities and Physicochemical Properties of Four Grape Musts from Different Varieties. *Food and Bioprocess Technology.* **6**: 2223-2229.

Falguera, V., Pagán, J., and Ibarz, A. (2011). Effect of UV irradiation on enzymatic activities and physicochemical properties of apple juices from different varieties. *LWT - Food Science and Technology.* **44**: 115-119.

Feng, M., Ghafoor, K., Seo, B., Yang, K., andPark, J. (2013). Effects of ultraviolet-C treatment in Teflon®-coil on microbial populations and physico-chemical characteristics of watermelon juice. *Innovative Food Science & Emerging Technologies.* **19**: 133-139.

Fernandes, F. A. N., Gallão, M. I., and Rodrigues, S. (2009). Effect of osmosis and ultrasound on pineapple cell tissue structure during dehydration. *J Food Eng.* **90**: 186-190.

Fernández-García, E., Carvajal-Lérida, I., Jarén-Galán, M., Garrido-Fernández, J., Pérez-Gálvez, A., and Hornero-Méndez, D. (2012). Carotenoids bioavailability from foods: From plant pigments to efficient biological activities. *Food Res Int.* **46**: 438-450.

Ferrari, G., Maresca, P., and Ciccarone, R. (2010). The application of high hydrostatic pressure for the stabilization of functional foods: Pomegranate juice. *J Food Eng.* **100**: 245-253.

Fonteles, T. V., Costa, M. G. M., de Jesus, A. L. T., de Miranda, M. R. A., Fernandes, F. A. N., and Rodrigues, S. (2012). Power ultrasound processing of cantaloupe melon juice: Effects on quality parameters. *Food Res Int.* **48**: 41-48.

Fratianni, A., Cinquanta, L., andPanfili, G. (2010). Degradation of carotenoids in orange juice during microwave heating. *LWT - Food Science and Technology.* **43**: 867-871.

Gasperi, F., Aprea, E., Biasioli, F., Carlin, S., Endrizzi, I., Pirretti, G., andSpilimbergo, S. (2009). Effects of supercritical CO2 and N2O pasteurisation on the quality of fresh apple juice. *Food Chem.* **115**: 129-136.

Géczi, G., Horváth, M., Kaszab, T., andAlemany, G. G. (2013). No Major Differences Found between the Effects of Microwave-Based and Conventional Heat Treatment Methods on Two Different Liquid Foods. *PLoS ONE.* **8**.

Geveke, D. J., Brunkhorst, C., andFan, X. (2007). Radio frequency electric fields processing of orange juice. *Innovative Food Science and Emerging Technologies.* **8**: 549-554.

Gómez, P. L., Welti-Chanes, J., and Alzamora, S. M. (2011). Hurdle technology in fruit processing. *Annual review of food science and technology.* **2**: 447-465.

Gómez-López, V. M., Devlieghere, F., Bonduelle, V., and Debevere, J. (2005). Factors affecting the inactivation of micro-organisms by intense light pulses. *J Appl Microbiol.* **99**: 460-470.

Gómez-López, V. M., Orsolani, L., Martínez-Yépez, A., and Tapia, M. S. (2010). Microbiological and sensory quality of sonicated calcium-added orange juice. *LWT - Food Science and Technology.* **43**: 808-813.

Grimi, N., Lebovka, N. I., Vorobiev, E., and Vaxelaire, J. (2009). Effect of a pulsed electric field treatment on expression behavior and juice quality of Chardonnay grape. *Food Biophysics.* **4**: 191-198.

Grimi, N., Mamouni, F., Lebovka, N., Vorobiev, E., and Vaxelaire, J. (2011). Impact of apple processing modes on extracted juice quality: Pressing assisted by pulsed electric fields. *J Food Eng.* **103**: 52-61.

Grimi, N., Praporscic, I., Lebovka, N., and Vorobiev, E. (2007). Selective extraction from carrot slices by pressing and washing enhanced by pulsed electric fields. *Separation and Purification Technology.* **58**: 267-273.

Guo, M., Wu, J., Xu, Y., Xiao, G., Zhang, M., andChen, Y. (2011). Effects on microbial inactivation and quality attributes in frozen lychee juice treated by supercritical carbon dioxide. *European Food Research and Technology.* **232**: 803-811.

Guerrero-Beltrán, J. A. and Barbosa-Cánovas, G. V. (2005). Reduction of Saccharomyces cerevisiae, Escherichia coli and Listeria innocua in apple juice by ultraviolet light. *J Food Process Eng.* **28**: 437-452.

Hart, E. J. and Henglein, A. (1985). Free radical and free atom reactions in the sonolysis of aqueous iodide and formate solutions. *J Phys Chem.* **89**: 4342-4347.

Hartyáni, P., Dalmadi, I., Cserhalmi, Z., Kántor, D., Tóth-Markus, M., and Sass-Kiss, A. (2011). Physical-chemical and sensory properties of pulsed electric field and high hydrostatic pressure treated citrus juices. *Innovative Food Science and Emerging Technologies.* **12**: 255-260.

Hartyáni, P., Dalmadi, I., and Knorr, D. (2013). Electronic nose investigation of *Alicyclobacillus acidoterrestris* inoculated apple and orange juice treated by high hydrostatic pressure. *Food Control.* **32**: 262-269.

Heinz, V., Toepfl, S., and Knorr, D. (2003). Impact of temperature on lethality and energy efficiency of apple juice pasteurization by pulsed electric fields treatment. *Innovative Food Science and Emerging Technologies.* **4**: 167-175.

Hsu, K., Tan, F., andChi, H. (2008). Evaluation of microbial inactivation and physicochemical properties of pressurized tomato juice during refrigerated storage. *LWT - Food Science and Technology.* **41**: 367-375.

Ibarz, A., Barbosa-Cánovas, G.V. (2003). Unit operations in food engineering. CRC Press. Boca Ratón, FL.

Ibarz, A., Pagán, J., Panadés, R., and Garza, S. (2005). Photochemical destruction of color compounds in fruit juices. *J Food Eng.* **69**: 155-160.

Icier, F. and Tavman, S. (2006). Ohmic heating behaviour and rheological properties of ice cream mixes. *Int J Food Prop.* **9**: 679-689.

Igual, M., Contreras, C., andMartínez-Navarrete, N. (2010a). Non-conventional techniques to obtain grapefruit jam. *Innovative Food Science & Emerging Technologies.* **11**: 335-341.

Igual, M., García-Martínez, E., Camacho, M. M., and Martínez-Navarrete, N. (2010b). Effect of thermal treatment and storage on the stability of organic acids and the functional value of grapefruit juice. *Food Chem.* **118**: 291-299.

Jabbar, S., Abid, M., Hu, B., Wu, T., Hashim, M. M., Lei, S., Zhu, X., andZeng, X. (2014). Quality of carrot juice as influenced by blanching and sonication treatments. *LWT - Food Science and Technology.* **55**: 16-21.

Jo, C., Ahn, D. U., andLee, K. H. (2012). Effect of gamma irradiation on microbiological, chemical, and sensory properties of fresh ashitaba and kale juices. *Radiat Phys Chem.* **81**: 1076-1078.

Jo, C. and Lee, K. H. (2012). Comparison of the efficacy of gamma and UV irradiation in sanitization of fresh carrot juice. *Radiat Phys Chem.* **81**: 1079-1081.

Kaur, C., George, B., Deepa, N., Jaggi, S., andKapoor, H. C. (2007). Viscosity and quality of tomato juice as affected by processing methods. *J Food Qual.* **30**: 864-877.

Kim, H. K., Leem, K. -., Lee, S., Kim, B. -., Hahm, Y. T., Cho, H. -., and Lee, J. Y. (2012). Effect of high hydrostatic pressure on immunomodulatory activity of cloudy apple juice. *Food Science and Biotechnology.* **21**: 175-181.

Kim, Y., Park, S., Cho, Y., and Park, J. (2001). Effects of combined treatment of high hydrostatic pressure and mild heat on the quality of carrot juice. *J Food Sci.* **66**: 1355-1360.

Kincal, D., Hill, W. S., Balaban, M., Portier, K. M., Sims, C. A., Wei, C. I., and Marshall, M. R. (2006). A continuous high-pressure carbon dioxide system for cloud and quality retention in orange juice. *J Food Sci.* **71**: C338-C344.

Knorr, D., Zenker, M., Heinz, V., andLee, D. (2004). Applications and potential of ultrasonics in food processing. *Trends in Food Science and Technology.* **15**: 261-266.

Laboissière, L. H. E. S., Deliza, R., Barros-Marcellini, A. M., Rosenthal, A., Camargo, L. M. A. Q., andJunqueira, R. G. (2007). Effects of high hydrostatic pressure (HHP) on sensory characteristics of yellow passion fruit juice. *Innovative Food Science & Emerging Technologies.* **8**: 469-477.

Lee, H., Kim, H., Cadwallader, K. R., Feng, H., andMartin, S. E. (2013). Sonication in combination with heat and low pressure as an alternative pasteurization treatment ï Effect on Escherichia coli K12 inactivation and quality of apple cider. *Ultrason Sonochem.* **20**: 1131-1138.

Lee, J. W., Kim, J. K., Srinivasan, P., Choi, J., Kim, J. H., Han, S. B., Kim, D., andByun, M. W. (2009). Effect of gamma irradiation on microbial analysis, antioxidant activity, sugar content and color of ready-to-use tamarind juice during storage. *LWT - Food Science and Technology.* **42**: 101-105.

Lee, S., Chung, H., and Kang, D. (2006). Combined treatment of high pressure and heat on killing spores of *Alicyclobacillus acidoterrestris* in apple juice concentrate. *J Food Prot.* **69**: 1056-1060.

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

Leizerson, S. and Shimoni, E. (2005a). Effect of ultrahigh-temperature continuous ohmic heating treatment on fresh orange juice. *J Agric Food Chem.* **53**: 3519-3524.

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

Lieu, L. N. and Le, V. V. M. (2010). Application of ultrasound in grape mash treatment in juice processing. *Ultrason Sonochem.* **17**: 273-279.

Lima, M., Heskitt, B. F., Burianek, L. L., Nokes, S. E., and Sastry, S. K. (1999). Ascorbic acid degradation kinetics during conventional and ohmic heating. *J Food Process Preserv.* **23**: 421-434.

Liu, Y., Zhao, X. Y., Zou, L., andHu, X. S. (2013). Effect of high hydrostatic pressure on overall quality parameters of watermelon juice. *Food Sci Technol Int.* **19**: 197-207.

Manzocco, L., Quarta, B., and Dri, A. (2009). Polyphenoloxidase inactivation by light exposure in model systems and apple derivatives. *Innovative Food Science & Emerging Technologies.* **10**: 506-511.

Marsellés-Fontanet, Á. R., Puig-Pujol, A., Olmos, P., Mínguez-Sanz, S., and Martín-Belloso, O. (2013). A Comparison of the Effects of Pulsed Electric Field and Thermal Treatments on Grape Juice. *Food and Bioprocess Technology.* **6**: 978-987.

Mert, M., Buzrul, S., andAlpas, H. (2013). Effects of high hydrostatic pressure on microflora and some quality attributes of grape juice. *High Pressure Research.* **33**: 55-63.

Min, S., Jin, Z. T., Min, S. K., Yeom, H., and Zhang, Q. H. (2003). Commercial-scale pulsed electric field processing of orange juice. *J Food Sci.* **68**: 1265-1271.

Mishra, B. B., Gautam, S., andSharma, A. (2011). Shelf Life Extension of Sugarcane Juice Using Preservatives and Gamma Radiation Processing. *J Food Sci.* **76**: M573-M578.

Morales-de la Peña, M., Salvia-Trujillo, L., Rojas-Graü, M. A., and 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 Science and Technology.* **43**: 872-881.

Morel-Salmi, C., Souquet, J., Bes, M., and Cheynier, V. (2006). Effect of flash release treatment on phenolic extraction and wine composition. *J Agric Food Chem.* **54**: 4270-4276.

Mullen, W., Marks, S. C., and Crozier, A. (2007). Evaluation of phenolic compounds in commercial fruit juices and fruit drinks. *J Agric Food Chem.* **55**: 3148-3157.

Nguyen, P. and Mittal, G. S. (2007). Inactivation of naturally occurring microorganisms in tomato juice using pulsed electric field (PEF) with and without antimicrobials. *Chemical Engineering and Processing: Process Intensification.* **46**: 360-365.

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

Odriozola-Serrano, I., Aguiló-Aguayo, I., Soliva-Fortuny, R., Gimeno-Añó, V., and Martín-Belloso, O. (2007). Lycopene, vitamin C, and antioxidant capacity of tomato juice as affected by high-intensity pulsed electric fields critical parameters. *J Agric Food Chem.* **55**: 9036-9042.

Odriozola-Serrano, I., Soliva-Fortuny, R., Hernández-Jover, T., and Martín-Belloso, O. (2009a). Carotenoid and phenolic profile of tomato juices processed by high intensity pulsed electric fields compared with conventional thermal treatments. *Food Chem.* **112**: 258-266.

Odriozola-Serrano, I., Aguiló-Aguayo, I., Soliva-Fortuny, R., and Martín-Belloso, O. (2013). Pulsed electric fields processing effects on quality and health-related constituents of plant-based foods. *Trends in Food Science and Technology.* **29**: 98-107.

Odriozola-Serrano, I., Soliva-Fortuny, R., and Martín-Belloso, O. (2009b). Impact of high-intensity pulsed electric fields variables on vitamin C, anthocyanins and antioxidant capacity of strawberry juice. *LWT - Food Science and Technology.* **42**: 93-100.

Odriozola-Serrano, I., Soliva-Fortuny, R., and Martín-Belloso, O. (2008a). Changes of health-related compounds throughout cold storage of tomato juice stabilized by thermal or high intensity pulsed electric field treatments. *Innovative Food Science and Emerging Technologies.* **9**: 272-279.

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

 ACCEPTED MANUSCRIPT

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

Orlowska, M., Koutchma, T., Grapperhaus, M., Gallagher, J., Schaefer, R., and Defelice, C. (2012). Continuous and Pulsed Ultraviolet Light for Nonthermal Treatment of Liquid Foods. Part 1: Effects on Quality of Fructose Solution, Apple Juice, and Milk. *Food and Bioprocess Technology.*: 1-13.

Oulé, K. M., Dickman, M., andArul, J. (2013). Properties of orange juice with supercritical carbon dioxide treatment. *Int J Food Prop.* **16**: 1693-1710.

Palgan, I., Caminiti, I. M., Muñoz, A., Noci, F., Whyte, P., Morgan, D. J., Cronin, D. A., and Lyng, J. G. (2011a). 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., Caminiti, I. M., Muñoz, A., Noci, F., Whyte, P., Morgan, D. J., Cronin, D. A., and Lyng, J. G. (2011b). Effectiveness of High Intensity Light Pulses (HILP) treatments for the control of Escherichia coli and Listeria innocua in apple juice, orange juice and milk. *Food Microbiol.* **28**: 14-20.

Pan, J., Wang, H., Xie, H., Yang, Y., and Zeng, Q. (2011). Effect of ultra high hydrostatic pressure on concentrations of limonene, A- terpineol and carvone in navel orange juice. *J Food Process Eng.* **34**: 728-745.

Paranjpe, S. S., Ferruzzi, M., and Morgan, M. T. (2012). Effect of a flash vacuum expansion process on grape juice yield and quality. *LWT - Food Science and Technology.* **48**: 147-155.

Patil, S., Torres, B., Tiwari, B. K., Wijngaard, H. H., Bourke, P., Cullen, P. J., O'Donnell, C. P., and Valdramidis, V. P. (2010a). Safety and quality assessment during the ozonation of cloudy apple juice. *J Food Sci.* **75**: M437-M443.

Patil, S., Valdramidis, V. P., Cullen, P. J., Frias, J., and Bourke, P. (2010b). Inactivation of *Escherichia coli* by ozone treatment of apple juice at different pH levels. *Food Microbiol.* **27**: 835-840.

Picouet, P. A., Landl, A., Abadias, M., Castellari, M., and Viñas, I. (2009). Minimal processing of a Granny Smith apple purée by microwave heating. *Innovative Food Science & Emerging Technologies.* **10**: 545-550.

Polydera, A. C., Stoforos, N. G., and Taoukis, P. S. (2003). Comparative shelf life study and vitamin C loss kinetics in pasteurised and high pressure processed reconstituted orange juice. *J Food Eng.* **60**: 21-29.

Praporscic, I., Lebovka, N., Vorobiev, E., and Mietton-Peuchot, M. (2007). Pulsed electric field enhanced expression and juice quality of white grapes. *Separation and Purification Technology.* **52**: 520-526.

Puértolas, E., López, N., Saldaña, G., Álvarez, I., andRaso, J. (2010). Evaluation of phenolic extraction during fermentation of red grapes treated by a continuous pulsed electric fields process at pilot-plant scale. *J Food Eng.* **98**: 120-125.

Puértolas, E., Saldaña, G., Condón, S., Álvarez, I., and Raso, J. (2009). A comparison of the effect of macerating enzymes and pulsed electric fields technology on phenolic content and color of red wine. *J Food Sci.* **74**: C647-C652.

Queiroz, C., Moreira, C. F. F., Lavinas, F. C., Lopes, M. L. M., Fialho, E., and Valente-Mesquita, V. L. (2010). Effect of high hydrostatic pressure on phenolic compounds, ascorbic acid and antioxidant activity in cashew apple juice. *High Pressure Research.* **30**: 507-513.

Rao, M. A. (1999). Rheology of Fluid and Semisolid Foods: Principles and Applications . Aspen Publishers, Gaithersburg.

Salvia-Trujillo, L., Morales-De La Peña, M., Rojas-Graü, A., and Martín-Belloso, O. (2011). Changes in water-soluble vitamins and antioxidant capacity of fruit juice-milk beverages as affected by high-intensity pulsed electric fields (HIPEF) or heat during chilled storage. *J Agric Food Chem.* **59**: 10034-10043.

Santhirasegaram, V., Razali, Z., andSomasundram, C. (2013). Effects of thermal treatment and sonication on quality attributes of Chokanan mango (*Mangifera indica* L.) juice. *Ultrason Sonochem.* **20**: 1276-1282.

Schilling, S., Alber, T., Toepfl, S., Neidhart, S., Knorr, D., Schieber, A., andCarle, R. (2007). Effects of pulsed electric field treatment of apple mash on juice yield and quality attributes of apple juices. *Innovative Food Science and Emerging Technologies.* **8**: 127-134.

Schilling, S., Toepfl, S., Ludwig, M., Dietrich, H., Knorr, D., Neidhart, S., Schieber, A., and Carle, R. (2008). Comparative study of juice production by pulsed electric field treatment and enzymatic maceration of apple mash. *European Food Research and Technology.* **226**: 1389-1398.

Seshadri, R., Weiss, J., Hulbert, G. J., andMount, J. (2003). Ultrasonic processing influences rheological and optical properties of high-methoxyl pectin dispersions. *Food Hydrocoll.* **17**: 191-197.

Shamsudin, R., Ling, C. S., Adzahan, N. M., andDaud, W. R. W. (2013). Rheological properties of ultraviolet-irradiated and thermally pasteurized Yankee pineapple juice. *J Food Eng.* **116**: 548-553.

Sila, D. N., Van Buggenhout, S., Duvetter, T., Fraeye, I., De Roeck, A., Van Loey, A., andHendrickx, M. (2009). Pectins in processed fruits and vegetables: Part II - Structure-function relationships. *Comprehensive Reviews in Food Science and Food Safety.* **8**: 86-104.

Ġimunek, M., Jambrak, A. R., Petrovic, M., Juretic, H., Major, N., Herceg, Z., Hruġkar, M., and Vukuġic, T. (2013). Aroma profile and sensory properties of ultrasound-treated apple juice and nectar. *Food Technology and Biotechnology.* **51**: 101-111.

Slavov, A., Karagyozov, V., Denev, P., Kratchanova, M., andKratchanov, C. (2013). Antioxidant activity of red beet juices obtained after microwave and thermal pretreatments. *Czech Journal of Food Sciences.* **31**: 139-147.

Song, H., Byun, M., Jo, C., Lee, C., Kim, K., and Kim, D. (2007). Effects of gamma irradiation on the microbiological, nutritional, and sensory properties of fresh vegetable juice. *Food Control.* **18**: 5-10.

Song, H., Kim, D., Jo, C., Lee, C., Kim, K., and Byun, M. (2006). Effect of gamma irradiation on the microbiological quality and antioxidant activity of fresh vegetable juice. *Food Microbiol.* **23**: 372-378.

Stewart, C. M., Tompkin, R. B., and Cole, M. B. (2002). Food safety: New concepts for the new millennium. *Innovative Food Science and Emerging Technologies.* **3**: 105-112.

Stinco, C. M., Fernández-Vázquez, R., Heredia, F. J., Meléndez-Martínez, A. J., andVicario, I. M. (2013). Bioaccessibility, antioxidant activity and colour of carotenoids in ultrafrozen orange juices: Influence of thawing conditions. *LWT - Food Science and Technology.* **53**: 458-463.

Suárez-Jacobo, Á., Rüfer, C. E., Gervilla, R., Guamis, B., Roig-Sagués, A. X., andSaldo, J. (2011). Influence of ultra-high pressure homogenisation on antioxidant capacity, polyphenol and vitamin content of clear apple juice. *Food Chem.* **127**: 447-454.

Sung, H. -., Song, W. -., Kim, K. -., Ryu, S., andKang, D. -. (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**: 147-153.

Supeno and Kruus, P. (2000). Sonochemical formation of nitrate and nitrite in water. *Ultrason Sonochem.* **7**: 109-113.

Tannenbaum, S. R., Archer, M. C., and Young, V. R. (1985). Vitamins and minerals. **In:**Food chemistry, pp. 488-493. Marcel Dekker Inc., New York, Ed.

Tikekar, R. V., Anantheswaran, R. C., and LaBorde, L. F. (2011). Ascorbic Acid Degradation in a Model Apple Juice System and in Apple Juice during Ultraviolet Processing and Storage. *J Food Sci.* **76**: 62-71.

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., Chenchaiah, M., andCullen, P. J. (2008). Effect of ozonation on the rheological and colour characteristics of hydrocolloid dispersions. *Food Res Int.* **41**: 1035-1043.

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., and Cullen, P. J. (2008a). Colour degradation and quality parameters of sonicated orange juice using response surface methodology. *LWT - Food Science and Technology.* **41**: 1876-1883.

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., and Cullen, P. J. (2008b). Kinetics of freshly squeezed orange juice quality changes during ozone processing. *J Agric Food Chem.* **56**: 6416-6422.

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., and Cullen, P. J. (2008c). Modelling colour degradation of orange juice by ozone treatment using response surface methodology. *J Food Eng.* **88**: 553-560.

Tiwari, B. K., O'Donnell, C. P., Patras, A., and Cullen, P. J. (2008d). Anthocyanin and ascorbic acid degradation in sonicated strawberry juice. *Journal of Agricultural and Food Chemistry.* **56**: 10071-10077.

Tiwari, B. K., O'Donnell, C. P., Brunton, N. P., and Cullen, P. J. (2009a). Degradation kinetics of tomato juice quality parameters by ozonation. *International Journal of Food Science and Technology.* **44**: 1199-1205.

Tiwari, B. K., O'Donnell, C. P., and Cullen, P. J. (2009b). Effect of non thermal processing technologies on the anthocyanin content of fruit juices. *Trends in Food Science and Technology.* **20**: 137-145.

Tiwari, B. K., O'Donnell, C. P., Muthukumarappan, K., and Cullen, P. J. (2009c). Anthocyanin and colour degradation in ozone treated blackberry juice. *Innovative Food Science and Emerging Technologies.* **10**: 70-75.

 ACCEPTED MANUSCRIPT

Tiwari, B. K., O'Donnell, C. P., Muthukumarappan, K., and Cullen, P. J. (2009d). Effect of sonication on orange juice quality parameters during storage. *International Journal of Food Science and Technology.* **44**: 586-595.

Tiwari, B. K., O'Donnell, C. P., Patras, A., Brunton, N., and Cullen, P. J. (2009e). Anthocyanins and color degradation in ozonated grape juice. *Food and Chemical Toxicology.* **47**: 2824-2829.

Tiwari, B. K., O'Donnell, C. P., Patras, A., Brunton, N., and Cullen, P. J. (2009f). Effect of ozone processing on anthocyanins and ascorbic acid degradation of strawberry juice. *Food Chemistry.* **113**: 1119-1126.

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., andCullen, P. J. (2009g). Inactivation kinetics of pectin methylesterase and cloud retention in sonicated orange juice. Innovative Food Science & Emerging Technologies. 10: 166-171.

Tiwari, B. K., Patras, A., Brunton, N., Cullen, P. J., and O'Donnell, C. P. (2010). Effect of ultrasound processing on anthocyanins and color of red grape juice. *Ultrason Sonochem.* **17**: 598-604.

Tolstoguzov, V. B. (1990). Ionic strength and poly ion charges. *International Food and Ingredients.* **2**: 8-9.

Tomlin, B. D., Jones, S. E., Teixeira, A. A., Correll, M. J., andReyes-De-Corcuera, J. I. (2014). Kinetics of viscosity reduction of pectin solutions using a pectinase formulation at high hydrostatic pressure. *J Food Eng.* **129**: 47-52.

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

Torregrosa, F., Esteve, M. J., Frígola, A., and Cortés, C. (2006). Ascorbic acid stability during refrigerated storage of orange-carrot juice treated by high pulsed electric field and comparison with pasteurized juice. *J Food Eng.* **73**: 339-345.

Torres, B., Tiwari, B. K., Patras, A., Wijngaard, H. H., Brunton, N., Cullen, P. J., and O'Donnell, C. P. (2011). Effect of ozone processing on the colour, rheological properties and phenolic content of apple juice. *Food Chem.* **124**: 721-726.

Tumpanuvatr, T. and Jittanit, W. (2012). The temperature prediction of some botanical beverages, concentrated juices and purees of orange and pineapple during ohmic heating. *J Food Eng.* **113**: 226-233.

Turk, M. F., Baron, A., and Vorobiev, E. (2010). Effect of pulsed electric fields treatment and mash size on extraction and composition of apple juices. *J Agric Food Chem.* **58**: 9611-9616.

Turk, M. F., Billaud, C., Vorobiev, E., and Baron, A. (2012a). Continuous pulsed electric field treatment of French cider apple and juice expression on the pilot scale belt press. *Innovative Food Science and Emerging Technologies.* **14**: 61-69.

Turk, M. F., Vorobiev, E., and Baron, A. (2012b). Improving apple juice expression and quality by pulsed electric field on an industrial scale. *LWT - Food Science and Technology.* **49**: 245-250.

Valappil, Z. A., Fan, X., Zhang, H. Q., andRouseff, R. L. (2009). Impact of thermal and nonthermal processing technologies on unfermented apple cider aroma volatiles. *J Agric Food Chem.* **57**: 924-929.

Vallverdú-Queralt, A., Odriozola-Serrano, I., Oms-Oliu, G., Lamuela-Raventós, R. M., Elez-Martínez, P., andMartín-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**: 3131-3138.

Vanamala, J., Cobb, G., Loaiza, J., Yoo, K., Pike, L. M., and Patil, B. S. (2007). Ionizing radiation and marketing simulation on bioactive compounds and quality of grapefruit (*Citrus paradisi* c.v. Rio Red). *Food Chem.* **105**: 1404-1411.

Velázquez-Estrada, R. M., Hernández-Herrero, M. M., Guamis-López, B., and Roig-Sagués, A. X. (2012). Impact of ultra high pressure homogenization on pectin methylesterase activity and microbial characteristics of orange juice: A comparative study against conventional heat pasteurization. *Innovative Food Science & Emerging Technologies.* **13**: 100-106.

Vervoort, L., Van der Plancken, I., Grauwet, T., Timmermans, R. A. H., Mastwijk, H. C., Matser, A. M., Hendrickx, M. E., and Van Loey, A. (2011). Comparing equivalent thermal, high pressure and pulsed electric field processes for mild pasteurization of orange juice: Part II: Impact on specific chemical and biochemical quality parameters. *Innovative Food Science & Emerging Technologies.* **12**: 466-477.

Vikram, V. B., Ramesh, M. N., andPrapulla, S. G. (2005). Thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. *J Food Eng.* **69**: 31-40.

Walkling-Ribeiro, M., Noci, F., Cronin, D. A., Lyng, J. G., and Morgan, D. J. (2009). Shelf life and sensory evaluation of orange juice after exposure to thermosonication and pulsed electric fields. *Food Bioprod Process.* **87**: 102-107.

Walkling-Ribeiro, M., Noci, F., Cronin, D. A., Lyng, J. G., and Morgan, D. J. (2009). Shelf life and sensory evaluation of orange juice after exposure to thermosonication and pulsed electric fields. *Food Bioprod Process.* **87**: 102-107.

Walkling-Ribeiro, M., Noci, F., Cronin, D. A., Lyng, J. G., and Morgan, D. J. (2008a). Inactivation of Escherichia coli in a tropical fruit smoothie by a combination of heat and pulsed electric fields. *J Food Sci.* **73**: M395-M399.

Walkling-Ribeiro, M., Noci, F., Cronin, D. A., Riener, J., Lyng, J. G., and Morgan, D. J. (2008b). Reduction of Staphylococcus aureus and quality changes in apple juice processed by ultraviolet irradiation, pre-heating and pulsed electric fields. *J Food Eng.* **89**: 267-273.

Wood, O. B. and Bruhn, C. M. (2000). Position of the American Dietetic Association: food irradiation. *Journal of the American Dietetic Association.* **100**: 246-253.

Wu, J., Gamage, T. V., Vilkhu, K. S., Simons, L. K., and Mawson, R. (2008). Effect of thermosonication on quality improvement of tomato juice. *Innovative Food Science and Emerging Technologies.* **9**: 186-195.

Yeom, H. W., Streaker, C. B., Howard Zhang, Q., and Min, D. B. (2000). Effects of pulsed electric fields on the quality of orange juice and comparison with heat pasteurization. *J Agric Food Chem.* **48**: 4597-4605.

Yildiz, H., Bozkurt, H., andIcier, F. (2009). Ohmic and conventional heating of pomegranate juice: Effects on rheology, color, and total phenolics. *Food Sci Technol Int.* **15**: 503-512.

Yousefi, S., Emam-Djomeh, Z., Mousavi, S. M. A., and Askari, G. R. (2012). Comparing the Effects of Microwave and Conventional Heating Methods on the Evaporation Rate and Quality Attributes of Pomegranate (Punica granatum L.) Juice Concentrate. *Food and Bioprocess Technology.* **5**: 1328-1339.

Zabetakis, I., Leclerc, D., and Kajda, P. (2000). The effect of high hydrostatic pressure on the strawberry anthocyanins. *J Agric Food Chem.* **48**: 2749-2754.

Zafra-Rojas, Q. Y., Cruz-Cansino, N., Ramírez-Moreno, E., Delgado-Olivares, L., Villanueva-Sánchez, J., and Alanís-García, E. (2013). Effects of ultrasound treatment in purple cactus pear (*Opuntia ficus-indica*) juice. *Ultrason Sonochem.* **20**: 1283-1288.

Zárate-Rodríguez, E., Ortega-Rivas, E., and Barbosa-Cánovas, G. V. (2000). Quality changes in apple juice as related to nonthermal processing. *J Food Qual.* **23**: 337-349.

Zen, J., Tsai, D., and Yang, H. (2002). Direct Determination of Vitamin C in Fruit Juices Using a Polyviologen-Modified Electrode. *Electroanalysis.* **14**: 1597-1600.

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

Zhang, S., Wang, X., Yu, Y., and Guo, H. (2010a). Effects of microwave treatment of raw apple on browning of apple juice. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering.* **26**: 347-351.

Zhang, S., Wang, X., Yu, Y., and Guo, H. (2010b). Effects of microwave treatment of raw apple on browning of apple juice. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering.* **26**: 347-351.

Zhang, S. Y. and Wen, Y. J. (2013). Microwave pre-treatment reduced the browning of peach juice. *Advanced Materials Research.* **774-776**: 614-620.

Zhang, Y., Gao, B., Zhang, M., Shi, J., and Xu, Y. (2010c). Pulsed electric field processing effects on physicochemical properties, flavor compounds and microorganisms of longan juice. *J Food Process Preserv.* **34**: 1121-1138.

Zhang, Y., Hu, X. S., Chen, F., Wu, J. H., Liao, X. J., and Wang, Z. F. (2008). Stability and colour characteristics of PEF-treated cyanidin-3-glucoside during storage. *Food Chemistry.* **106**: 669-676.

Zhou, L., Wang, Y., Hu, X., Wu, J., andLiao, X. (2009). Effect of high pressure carbon dioxide on the quality of carrot juice. *Innovative Food Science and Emerging Technologies.* **10**: 321-327.

Zhu, Z., Bals, O., Grimi, N., Ding, L., andVorobiev, E. (2013). Qualitative characteristics and dead-end ultrafiltration of chicory juice obtained from pulsed electric field treated chicories. *Industrial Crops and Products.* **46**: 8-14.

Table 1. Effect of selected alternatives to conventional thermal treatments in fruit-juice processing on their polyphenol content.

UV lightLaboratory Enhancement UV dose: 2.158 J/m2
Treatment length: 30-60 min Bhat et al. 2011a
No significant differences UV dose: 3.88•10−7 E/min
Treatment length: 20-120 min Falguera et al. 2011
Depletion UV dose: 2.1 mW/cm2 Bakowska et al. 2003
HILP Laboratory No significant differences Light dose:1.17-5.1 J/cm2/pulse
Pulse width: 360 µs
Treatment length: 2-8 s Palgan et al. 2011,Pataro et al. 2011, Caminiti et al. 2009
Depletion Light dose: 1.313 J/cm2/pulse
Energy dosage: 3.3 J/cm2
Pulse width: 360 µs Caminiti et al. 2012
γ-irradiation Laboratory No significant differences Irradiation dose: 5 kGy Mishra et al. 2011
PEF Laboratory, Pilot plant and industrial scale Enhancement Electric field: 0.4-3 kV/cm
Pulse rise time: 100-1000 µs
Treatment length: 10-100 ms
Bipolar mode Grimi et al. 2009, Grimi et al. 2011, Schilling et al. 2008
Depletion Electric field: 0.45-1 kV/cm
Pulse rise time: 10-32 ms
Treatment length: 100 µs
Bipolar mode Turk et al. 2010, Turk et al. 2012a

		No significant differences	Electric field: 0.6-35 kV/cm	
Pulse rise time: 0.2 - 100 µs				
Treatment length: 75 µs - 23 ms				
Bipolar mode	Bi et al. 2013, Odriozola-Serrano et al. 2009, Morales-de la Peña et al. 2010, Odriozola-Serrano et al. 2008a, Odriozola-Serrano et al. 2008b, Turk et al. 2012b			
OH	Laboratory	Enhancement	Electric field:10-40 kV/cm	
Treatment length: 0-12 min				
Temperature. 90°C	Yildiz et al. 2009			
MW	Laboratory	No significant differences	Microwave power: 435-850 W	
Frequency: 2450 MHz				
Treatment length: 15-60 s				
Temperature: 70-80°C	Picouet et al. 2009, De Ancos et al. 1999			
Ultrasound	Laboratory	Enhancement	Wave amplitude: 24-60 µm/40-100%	
Power: 1500 W				
Frequency: 20-40 kHz				
Treatment length: 2-90 min				
Mode: pulsed and continuous	Santhirasegaram et al. 2013, Tiwari et al. 2010,Zafra-Rojas et al. 2013,Abid et al. 2013, Bhat et al. 2011b			
Technique	Scale	Effect on polyphenols	Optimun parameters	References

Abbrevations

UV Ultraviolet

HILP High Intensity Light Pulses

PEF Pulsed Electric Fields

OH Ohmic Heating

MW Microwave

HHP High Hydrostatic Pressure

SC-CO_2 Supercritical CO_2

FVE Flash-Vacuum Expansion

 ACCEPTED MANUSCRIPT

Table 2. Effect of selected alternatives to conventional thermal treatments in fruit-juice processing on their carotenoids content.

Technique Scale Effect on polyphenols Optimun parameters References
PEF Laboratory, Pilot plant and industrial scale No significant differences Electric field: 25-40 kV/cm
Pulse rise time:1-7 µs
Treatment length: 30-1500 µs
Bipolar mode Odriozola-Serrano et al. 2009a, Odriozola-Serrano et al. 2009b, Torregrosa et al. 2006, Cortés et al. 2006, Vervoort et al. 2011
Conversion Electric field: 35 kV/cm
Pulse rise time:1-7 µs
Treatment length: 100-2500 µs
Bipolar mode Odriozola-Serrano et al. 2007, Odriozola-Serrano et al. 2008a, Odriozola-Serrano et al. 2008b, Odriozola-Serrano et al. 2009a, Oms-Oliu et al. 2009
MW Laboratory Depletion Microwave power: 435-850 W
Frequency: 2450 MHz
Treatment length: 30s-10 min
Temperature: 60-70°C Fratianni et al. 2010, De Ancos et al. 1999, Kim et al. 2001
Ultrasound Laboratory Enhancement Power: 130 W
Frequency: 40 kHz
Treatment length: 15-60 min Santhirasegaram et al. 2013, Demirdöven and Baysal. 2009
HHP Laboratory Enhancement Pressure: 300 MPa
Treatment length: 10 min
Temperature: 4-25°C Hsu et al. 2008

No significant differences	Pressure: 395-445 MPa
Treatment length: 8-11 min	
Temperature: 70°C	Kim et al. 2001

Abbrevations

PEF Pulsed Electric Fields

MW Microwave

HHP High Hydrostatic Pressure