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Preservation effects of High Pressure processing on overall quality of fruit juices

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Abstract
Juice is defined in the most general sense as the extractable fluid contents of cells or tissues. Juices, in general, are good sources of vitamins and minerals and other valuable components to human health. Fruit juices are highly perishable commodity and are thermally processed to aid their preservation. However, heat processing particularly under severe conditions may induce several chemical and physical changes that impair the organoleptic properties and may reduce the content or bioavailability of some bioactive compounds.In pasteurization, sterilization and blanching, the use of heat can destroy nutrients such as thermally labile vitamins and also components responsible for product flavor and taste.Non thermal technologies are preservation treatments that are effective at ambient or sub-lethal temperatures, thereby minimizing negative thermal effects on fruit juice nutritional and quality parameters.High pressure processing (HPP) is a non-thermal food preservation technique for microbial and enzyme inactivation with reduced effects on nutritional and quality parameters when compared to thermal treatments.High Pressure Processing can provide safe product with reduced processing time and maintain maximum fresh-like flavor and taste in the product due to the lower processing temperatures. Moreover, it is environment friendly since it requires only electrical energy and no waste by-products generated. Therefore, High Process-treated fruit juices are superior in fruit juice preservation in the areas of microbial inactivation, sensory improvement and shelf-life extension to those of juices preserved in the traditional way by heat treatment.

Keywords: High Pressure Processing, Fruit Juices, Non- Thermal Technology, Heat Sensitive
Abbreviations: **HPP:** High Pressure Processing, **HPT:** High Pressure Treatment, **POD:** Peroxidase, **PPO:** Polyphenol Oxidase, **LOX:** Lipoxygenases, **AA:** Ascorbic Acid

1. Introduction

The world's fruit production is about 868.085 million metric ton in 2018 (FAO STAT, 2018) [31]. The India's fruit production is about 97.358 million metric tons in 2017-18 (Indian Horticulture Database, 2018) [43]. In India, out of the total production of fruits, nearly 76% is consumed in fresh form, while wastage and losses account for 20–22%. Only 4% of fruit production is being processed (Sharma *et al.*, 2017) [90]. India is the second largest producer of fruits in the world, because India consists of diverse agro-climatic conditions and allows the production of various tropical (mango, coconut, cashew), subtropical (sugar orange, litchi, dates) and temperate (apple, pear, almond) fruits. Fruits are important sources of essential dietary nutrients such as vitamins, minerals and fibers. Since the moisture content of the fresh fruits is more than 80% (wb); they are highly perishable commodities. According to the estimates, nearly 30% of the fruits are lost due to spoilage, due to handling, transportation and lack of cold storage and processing techniques (Sing *et al.*, 1994) [85]. Food preservation has an important role in the conservation and better utilization of fruits in order to avoid the glut and utilize the surplus during the off-season. It is necessary to employ modern methods to extend storage life for better distribution and also processing techniques to preserve them for utilization in the off-season (Vidhya *et al.*, 2005) [100]. The production of fruit and vegetable juices is important both from the human health and commercial standpoints. The availability of nutritious components from fruits and vegetables to a wide range of consumers is thus facilitated throughout the year by the marketing of their juices. The production of fruit juices is one of the ways to make better use of these fruit crops (Sharma *et al.*, 2015) [89].

Fruit Juices Preservation by convectional heating alters or changes the nutritional and organoleptic attributes. Therefore, an alternative non thermal technique is required which is damage or alter minimum attributes of fruit juices and inactive or eliminate pathogenic microorganisms and food spoilage microorganisms. High Pressure Processing is novel non thermal technique, which is used for shelf life extension and makes various fruit juices as safe. High Pressure Processing is carried out at room temperature. Thus, it reduces the energy consumption associated with heating and cooling of the juices. Furthermore, High Pressure Processing is environmental friendly processing and low risk of contamination (Srinivas *et al.*, 2018) [88].

2. Current market scenario of fruit juices
Juice is defined in the most general sense as the extractable fluid contents of cells or tissues (Bates *et al.*, 2001) [9]. Juices, in general, are good sources of vitamins and minerals and other valuable components to human health (USDA, 2012) [97]. Consumption of juices per capita in India is very low. It is estimated at a fraction of a liter i.e. 20 ml where developed countries have attained a consumption level of 1500 ml. The juice segment is fast growing @ 21.7% per annum amongst all segments in India. The juices category was valued at INR 18,949.2 m ($459.2m) in 2012, representing a compound annual growth rate (CAGR) of 20% since 2005. (DTI) [30]

3. Health benefits
Consumer demand for nutritious foods such as fresh cut fruits and unpasteurized fruit juices has increased in the last decades owing to their low content of sodium, cholesterol and fat and high concentration of vitamin C, polyphenols, and antioxidants that play important role in the prevention of heart diseases, cancer, and diabetes (Kumar *et al.*, 2009, Patrignani *et al.*, 2010, Mosqueda-Melgar *et al.*, 2012) [47, 67, 59]. Juices are rich in vitamin B complex, vitamin C, folic acid, citric acid potassium and excellent sources of bioavailable antioxidant, phyto-chemicals (Mathur *et al.*, 1996, Franke *et al.*, 2005, Deshpande *et al.*, 2008, Penniston *et al.*, 2008, Ktare *et al.*, 2011, Milind *et al.*, 2011) [56, 35, 27, 61, 46, 57]. Juices significantly improves blood lipid profiles in people affected with hypercholesterolemia (Kurowska *et al.*, 2000, Deshpande *et al.*, 2007, Mohale *et al.*, 2008) [48, 28, 58], protective against stroke (Feldrnan 2001)[34]; anti-tumour, antiviral, anti-proliferative and anti-HIV activities (Ahmad *et al.*, 2011) [1], offset the oxidative stress (Ghanim *et al.*, 2010) [38] and its intake has been consistently associated with reduced risk of many cancer types (Brock *et al.*, 1998, Chan *et al.*, 2005, Kwan *et al.*, 2004, Maserejian 2006, Lewis 2009, Uzcudun *et al.*, 2002, Radosavljevic *et al.*, 2004, Wu *et al.*, 2009) [14, 18, 49, 55, 52, 98, 74,102].

4. Juice production
The process starts with sound fruit, freshly harvested from the field or taken from refrigerated or frozen storage. Washing is usually necessary to remove dirt and foreign objects and may be followed by a sanitation step to decrease the load of contaminants. Sorting to remove decayed and moldy fruit is also necessary to make sure that the final juice will not have a high microbial load, undesirable flavors, or mycotoxin contamination. For most fruits, pulping will be required prior to juice extraction. Enzymes might also be included before the mash is transferred to the extraction stage. Juice extraction can be performed by pressing or by enzymatic treatment followed by decanting. The extracted juice will then be treated according to the characteristics of the final product. For clear juices, complete depectinization by addition of enzymes, fine filtration, or high speed centrifugation will be required to achieve visual clarity. The next step is usually non thermal processing to achieve a safe and stable juice and final packaging (Downing *et al.*, 1996) [29].

5. Processing of juices
Fruits are highly perishable commodity and are thermally processed to aid their preservation. They are widely processed into juices, smoothies, purees, nectar etc. apart from dehydrated and canned (whole or in pieces) (Pereira *et al.*, 2010) [69]. However, heat processing particularly under severe conditions may induce several chemical and physical changes that impair the organoleptic properties and may reduce the content or bioavailability of some bioactive compounds (Patras *et al.*, 2009b, Patras *et al.*, 2010, Rawson *et al.*, 2010, Rawson *et al.*, 2011) [65, 66, 79, 80]. Therefore, there is a demand for mild processing technologies such as high pressure processing, irradiation, pulsed electric fields, power ultrasound, ozone and oscillating magnetic fields etc.

Non thermal technologies are preservation treatments that are effective at ambient or sub-lethal temperatures, thereby minimizing negative thermal effects on fruit juice nutritional and quality parameters (Rupasinghe *et al.*, 2012) [82]. In addition to their possible beneficial effects on nutritional and bioactive content many of these novel technologies are more cost-efficient and environment friendly for obtaining premium quality juices which have led to their revival and commercialization (Butz *et al.*, 2002, Piyasena *et al.*, 2003, Vikram *et al.*, 2005) [15, 70,101].

The main requirement that these new technologies must meet is to ensure product microbial safety while preserving sensory and nutritional characteristics to obtain products more similar to fresh foods. In pasteurization, sterilization and blanching, the use of heat can destroy nutrients such as thermally labile vitamins and also components responsible for product flavor and taste. It can also produce some undesirable compounds originated from Maillard reaction and caramelization. High hydrostatic pressure, alone or in combination with moderate heat treatment, has been investigated to obtain products of high quality and micro-biological stability (Cheftel *et al.*, 1995) [19].

6. Description of High Pressure Processing Technology
Various physical and chemical changes result from the application of pressure. Generally, physical compression during pressure treatment results in a volume reduction and an increase in temperature and energy (Heremans *et al.*, 2003) [42]. In predicting the effect of High Pressure Processing on fruit juices, it is necessary to consider the net combined pressure temperature effect of the process. The following principles govern the behavior of foods under pressure.

Le Chatelier's principle: Any phenomenon (phase transition, change in molecular configuration, chemical reaction) accompanied by a decrease in volume is enhanced by pressure. Accordingly, pressure shifts the system to that of lowest volume (Farkas *et al.*, 2000) [32].

Isostatic principle: Pressure is uniformly distributed throughout the entire sample, whether in direct contact with the pressurizing medium or insulated from it in a flexible container. Thus, the process time is independent of sample size and shape, assuming uniform thermal distribution within the sample.

Process temperature during pressure treatment can be specified from below 0 °C (to minimize any effects of adiabatic heat) to above 100 °C. Pressures used in the High

Pressure Processing of juices appear to have little effect on covalent bonds thus; juices subjected to HPP treatment at or near room temperature will not undergo significant chemical transformations due to the pressure treatment itself. HPP may be combined with heat to achieve an increased rate of inactivation of microbes and enzymes. Chemical changes in the juices generally will be a function of the process temperature and time selected in conjunction with the pressure treatment (Tauscher 1998, Tauscher 1999) [93, 94]. The temperature of water increases about 3°C for every 100 MPa pressure increase at room temperature (25°C). On the other hand, fats and oils have a heat of compression value of 8–9°C/100 MPa, and proteins and carbohydrates have intermediate heat of compression values (Rasanayagam *et al.*,2003, Parish 1998) [77, 62].

7. Equipment for HPP Treatment of fruit juices

HPP is primarily practiced as a batch process where pre-packaged fruit juices are treated in a chamber surrounded by water or another pressure-transmitting fluid. Semi-continuous systems have been developed for pump-able fruit juices where the product is compressed without a container and subsequently packaged "clean" or aseptically. The primary components of an HPP system include a pressure vessel; closure(s) for sealing the vessel; a device for holding the closure(s) in place while the vessel is under pressure (e.g., yoke); high-pressure intensifier pump(s); a system for controlling and monitoring the pressure and (optionally) temperature; and a product-handling system for transferring product to and from the pressure vessel. Normally, perforated baskets are used to insert and remove pre-packaged food products from the pressure vessels. Systems also have provisions for filtering and reusing the compression fluid (usually water or a food-grade solution).Liquid foods can be processed in a batch or semi-continuous mode.

For batch operation, packaged food is loaded into the pressure vessel, the vessel is sealed, and process water is pumped into the vessel to displace any air. When the vessel is full, the pressure relief valve is closed, and water is pumped into the vessel until the process pressure is reached. The rate of compression is directly proportional to the horsepower of the low pressure pump driving the intensifier. When the process time is completed, the pressure relief valve is opened and the water used for compression is allowed to expand and return to atmospheric pressure. The vessel is opened and the packaged food is removed and is ready for shipment. A 100-horsepower pump can bring a 50-liter vessel to an operating pressure of 680 MPa in 3-4 min. Compression time is a function of pump horsepower. Work must be supplied to compress water at pressures above 200 MPa. A filled 100-liter vessel will require an additional 15 liters of water to bring it to a pressure of 680 MPa.

Semi continuous operation requires two or more pressure vessels, each equipped with a free-floating piston that allows each vessel to be divided into two chambers. One chamber is used for the juice; the other for the pressure-transmitting fluid. The basic operation involves filling one chamber with the fruit juice to be treated. The fill valve is closed and then pressure-transmitting fluid is pumped into the second chamber of the vessel on the opposite side of the floating piston. Pressurization of the fluid in this second chamber results in compression of the liquid food in the first. After an appropriate holding time, the pressure is released from the second chamber. The product discharge valve is opened to discharge the contents of the first chamber, and a low-pressure pump injects pressure-transmitting fluid into the second chamber, which pushes on the piston and expels the contents of the product chamber through the discharge valve. The treated juice is directed to a sterile tank from which sterile containers can be filled aseptically. Typically, three pressure vessels are used to create a semi-continuous system capable of delivering a continuous product output. This is accomplished by operating the three vessels such that one is loading, one is compressing, and one is discharging at any point in time (Farkas *et al.*, 2000) [32].

8. Pressure – temperature effect

During the compression phase (T_1~T_2) of pressure treatment, fruit juices experience a decrease in volume as a function of the pressure. Both pure water and fruit juices subjected to a 600 MPa treatment at ambient temperature will experience about a 15% reduction in volume.

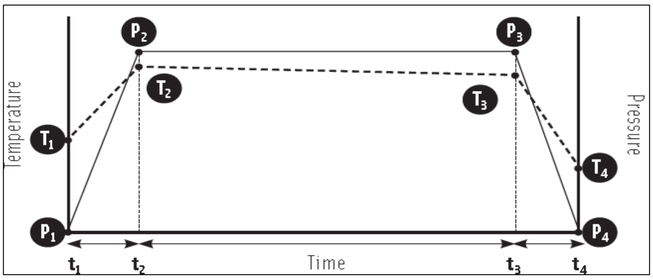

Fig 1: Pressure temperature effect on juices in High Pressure Processing treatment

The product is held under pressure for a certain time (T_2~T_3) before decompression (T_3~T_4). Upon decompression, the product will usually expand back to its initial volume (Farkas *et al.*, 2000) [32]. In practice, however, the product will return to a temperature (T_4) slightly lower than its initial temperature (T_1) as a result of heat losses during the compression (elevated temperature) phase (Fig. 1). The temperature increase in juices under pressure is dependent on factors such as final pressure, product composition, and initial temperature (Rasanayagam *et al.*, 2003, Patazca *et al.*, 2007) [77, 63].

9. Microbial Efficacy

High-pressure treatments, in general, are effective in inactivating most vegetative pathogenic and spoilage microorganisms at pressures above 200 MPa at chilled or process temperatures less than 45°C, but the rate of inactivation is strongly influenced by the peak pressure (Patterson *et al.*, 2005, Lau *et al.*, 2000) [68, 51]. The pressure resistance of vegetative microorganisms often reaches a maximum at ambient temperatures, so the initial temperature of the food prior to HPP can be reduced or elevated to improve inactivation at processing temperature (i.e., temperature at pressure). The extent of inactivation also depends on the type of microorganism, food composition, pH, and water activity (Cheftel *et al.*, 1995) [19]. HPP causes damage to cell membranes and denatures some intracellular proteins leading to cell death. Reduced pH is generally synergistic with pressure in eliminating microorganisms. Reduced water activity, however, tends to inhibit pressure inactivation with noticeable retardation as the water activity falls below ~ 0.95. Most yeasts are inactivated by exposure to 300–400 MPa at 25°C within a few minutes. Pressure inactivation of molds follows a pattern similar to yeast.

Among viruses, the high degree of structural diversity is reflected in their wide range of pressure resistances (Smelt, 1998) [86]. Bacterial spores can be difficult to inactivate using HPP, and require higher pressures, process temperatures, and holding times as compared to vegetative cells. Bacterial spores are often resistant to pressures above 1,000 MPa at ambient temperatures (Cheftel *et al.*, 1995) [19]. More research is needed to characterize the combined pressure-thermal resistance of pathogenic and spoilage microorganisms as a function of the food matrix, pH, and water activity (Balasubramaniam *et al.*, 2008) [6].

10. High Pressure Processing (HPP) of Fruit juices

This technology has been studied by many authors as a non-thermal food preservation technique, especially for fruit juices. High pressure processing (HPP) is a non-thermal food preservation technique for microbial and enzyme inactivation with reduced effects on nutritional and quality parameters when compared to thermal treatments. HPP is derived from material science in which juices are treated above 100 MPa (Rastogi *et al.*, 2007) [78]. Previously, using of HPP as a partial or total substitute for thermal food processing has been proposed for many vegetable juices. High pressure processing (HPP) uses pressures up to 1000 MPa, with or without heat, to inactivate harmful microorganisms in food products (Ramaswamy *et al.*, 2005) [76]. The application of High Pressure Processing in food area started from 1900s when Hite and other researchers applied High Pressure Processing on the preservation of milk, fruits and vegetables. However, it takes a long time for the commercial products to emerge in the market. In 1990, the first High Pressure Processing processed fruit jams were sold in the Japanese market. Subsequently, High Pressure Processing processed commercial products including fruit juices and beverages, vegetable products, among others, have been produced in North America, Europe, Australia, and Asia (Balasubramaniam *et al.*, 2008) [6]. High Pressure Processing is proven to meet the FDA requirement of a 5-*log* reduction of microorganisms in fruit juices and beverages without sacrificing the sensory and nutritional attributes of fresh fruit juices (San Martín *et al.*, 2002) [83]. Compared with thermal processing, High Pressure Processing has many advantages. It can provide safe product with reduced processing time. It can maintain maximum fresh-like flavor and taste in the product due to the lower processing temperatures. Moreover, it is environmentally friendly since it requires only electrical energy and no waste by-products generated (Ramaswamy *et al.*, 2003, Toepfl *et al.*, 2006) [76, 95]. Due to these advantages, High Pressure Processing has been widely used in food product preservation including fruit and beverages in the areas of microbial inactivation and shelf-life extension.

10.1 Effect of High Pressure Processing (HPP) on microbial quality of juices

Spoilage of fruit juices is primarily owing to the proliferation of their natural acid tolerant and osmophilic microflora (Bevilacqua *et al.*, 2012) [12]. Fresh fruit juices are more susceptible to spoilage because fluid contents are in touch with air and microorganisms from the environment during the time of handling (Mosqueda-Melgar *et al.*, 2012) [59].Various papers focused on the efficacy of High Pressure Processing to inactivate foodborne pathogens and spoiling microorganisms as *Escherichia coli*, *Listeria monocytogenes*, *Yersinia enterocolitica*, *Staphylococcus aureus*, *Salmonella typhimurium*, *Alicyclobacillusacidoterrestris* and *Bacillus subtilis* and yeasts *Yarrowialipolytica*, *Candida utilis* and *Saccharomyces cerevisiae*, *Pichiamembranifaciens* and *Rhodotorulabacarum* in fruit juices.

Bermudez *et al.* (2011) showed that mesophiles in fresh mango nectar were inactivated up to 4 log during come-up time of pressure application. The treatment at 345 and 414 MPa for 2 and 1 min, respectively, inactivated all viable Escherichia coli. The highest inactivation of mesophiles (7 log) was reported at 414 MPa after 4 min. In another study for processing of cantaloupe juice. The microbial count of juice after HPT (500 MPa, 20 min) was reduced to 100 CFU/100 ml and the activities of POD, PPO, and LOX were significantly lowered without change in sensory quality. Santos *et al.*, (2012) indicated that pomegranate juice after HPT (>350 MPa, 150 s) resulted in a reduction of the microbial load around 4.0 log cycles, and the microbial populations (aerobic mesophilic bacteria as well as molds and yeasts) were below the detection limit during the entire storage period at 4 °C for more than 35 days (Table 1). Buzrul *et al.*, (2008a) demonstrated that pineapple juice subjected to pulsed HPT (300 MPa, 20 °C, 60s, 5 pulses) resulted in significant inactivation of *Escherichia coli* and *Listeria innocuous* at lower pressure values than the ones used in commercial applications (>400 MPa). However, the pressure-treated juice stored at 4°C, 20°C and 37°C up to 3 weeks led to an increase in the level of microbial inactivation and no injury recovery of the bacteria were detected. HPT (552 MPa, 5 min) of mango juice with added ascorbic acid and phosphoric acid (pH 3.5) resulted in reduced rates of browning during storage at 3 °C for 1 month without any microbial growth (Guerrero-Beltrán *et al.*, 2006) [39].

Table 1: HPP inactivation of microorganisms in different fruit juices

Products	Microorganism	Treatment parameters	*Log* reduction	Sources
Orange juice	*Escherichia coli* O157: H7	550 MPa, 30 ºC, 5 min	6	Linton *et al.*, 1999 [53]
Apple juice	*Listeria monocytogenes*	200 MPa, 20 ºC, 5 min	2.8	Préstamo *et al.*, 1999 [73]
Apple juice	*Escherichia coli* 29055	400 MPa, 25ºC	>5	Rasanayagam *et al.*, 2003 [77]
Apple juice	*Escherichia coli, Listeria innocua, Salmonella*	545 MPa, 1 min	5	Avure Technologies [5]
Orange juice	*Escherichia coli, Listeria innocua*	241 MPa, 3 min	5	Guerrero-Beltran *et al.*, 2011 [40]

10.2 Effect of High Pressure Processing on Sensory quality of fruit juices

10.2.1 Effect of high pressure processing on color

HP treatment (at low and moderate temperatures) has a limited effect on pigments (e.g. chlorophyll, carotenoids, anthocyanins, etc.) responsible for the color of fruits juices. The color compounds of High Pressure processed fruit juices can, however, change during storage due to incomplete inactivation of enzymes and microorganisms, which can result in undesired chemical reactions (both enzymatic and non-enzymatic) in the food matrix. Chlorophylls a and b have different stabilities towards pressure and temperature. At room temperature, chlorophylls a and b exhibit extreme pressure stability but at temperatures higher than 50°C, High Pressure treatment affects their stability for example, a significant reduction in the chlorophyll content of broccoli juice (Butz *et al.*, 2002, Van Loey *et al.*, 1998) [16, 99]. The temperature dependency of the degradation rate constant of chlorophyll a is higher than that of chlorophyll b. At a constant pressure level, the values of the degradation rate constants of chlorophylls increase with increasing temperature (Van Loey *et al.*, 1998) [99]. The pressure dependency of the degradation rate constant of chlorophyll b at 70°C is higher than that of chlorophyll. For example, elevating pressure from 200 to 800 MPa accelerates the degradation of chlorophyll a and chlorophyll b of broccoli juice by 19.4% and 68.4%, respectively (Van Loey *et al.*, 1998) [99]. Carotenoids are important for the orange yellow and red appearance of fruit juices. Carotenoids are rather pressure stable. High Pressure treatment increases the extraction yields of carotenes from the plant matrix (De Ancos *et al.*, 2000, Garcia *et al.*, 2001a, Garcia *et al.*, 2001b, Tauscher 1998) [25, 35, 36, 93]. The colour of tomato juice remained unchanged after High Pressure treatment (up to 700 MPa) at 65 °C even for 1 h (Rodrigo *et al.*, 2007) [81]. Anthocyanins are water-soluble vacuolar flavonoid pigments responsible for the red to blue colour of fruit juices. Anthocyanins are stable during HP treatment at moderate temperature, for example, pelargonidin-3- glucoside and pelargonidin-3-rutinoside in red raspberry (*Rubusidaeus*) and strawberry (*Fragaria x ananassa*) juices during High Pressure treatment at 800 MPa (18-22°C/15 min) (Garcia-Palazon *et al.*, 2004) [37].

Besides the instability of colour pigments, browning plays an important role in the discoloration of HP-treated food products. For example in white grape juice after High Pressure treatment at 400 MPa/2°C, 500 MPa/2°C or 400 MPa/40°C/10 min (Daoudi *et al.*, 2002) [24] or in mango pulps after HP treatments at 100-400 MPa/20°C/15 or 30 min (Ahmed *et al.*, 2005)[2]. Ahmed *et al.*, (2005) [2] observed that colour parameters such as (a/b), C and h values of mango pulps remained constant after HP treatment indicating pigment stability, while increasing pressure intensity decreased the value of ΔE. Polydera *et al.* (2003) [71] found discoloration (based on L*, a* and b* values) of pressure-treated (500 MPa/35°C/5 min) reconstituted orange juice during storage (0, 10, 15°C for 120 days) and the degradation trend was not significantly different between pressure and thermally treated juices. Similar results were observed by the same authors (Polydera *et al.*, 2005) [72] in pressurized (600 MPa/40°C/4 min) navel orange juice.

10.2.2 Effect of high pressure processing on flavor

It is generally assumed that the fresh flavor of fruit juices is not altered by high-pressure processing, since the structure of small molecular flavor compounds is not directly affected by high pressure. This has been observed, by means of both chemical and sensory analysis, in a number of studies where strawberry juice (Lambert *et al*, 1999) [50], mandarin juice (Takahashi, 1993) [91], orange lemon carrot juice (Garcia *et al.*, 2001a) [36], white grape juice (Daoudi *et al.*, 2002) [24] and guava juice (Yen *et al.*, 1999) [104] have been treated at pressures of 200-600 MPa combined with ambient temperature. The finding on better flavor retention of HP processed (600 MPa/ambient temperature/5 min) strawberry juice in comparison with heat-treated (80°C/5 min) juice has been supported by a study where an electronic nose detector was used to analyze the volatiles of the treated juice. High Pressure treated strawberry juice differed from heat-treated and unprocessed strawberry juice. Cross validation of the electronic nose data showed that heat treatment changed volatile compounds more than high-pressure processing. Corresponding results were reported for similarly processed raspberry and black currant juices (Dalmadi *et al.*, 2007) [23].The taste of High Pressure treated orange juice was judged better than traditional heat pasteurized orange juice [62, 71, 72] and the typical off-flavor of heat-treated mandarin juice was not detected in HP-treated (400 MPa/ambient temperature/ 10 min) juice (Takahashi *et al.*, 1993) [91]. Another shelf-life study showed that the sweetness and acidity of the High Pressure treated (500 MPa/ 2 °C/10 min) grape juice were maintained for 60 days during storage at 4°C but fresh fruit and grass aroma were slightly reduced during storage (Daoudi *et al.*, 2002) [24]. Similar results were observed for High Pressure treated guava juices. The volatile flavor compounds inHigh Pressure treated (600 MPa/25°C/ 15 min) guava juice remained stable during 30 days storage at 4°C, but changes in the concentrations of volatiles were observed after 60 days storage. The concentrations of methanol and ethanol increased and the concentrations of many ester and aldehyde compounds decreased probably due to residual enzyme activity (Yen *et al.*, 1999) [104].

10.3 Effect of High Pressure processing on Nutritional quality of fruit juices

Yen and Lin (1996) investigated the effects of high pressures and thermal pasteurization on ascorbic acid (AA) content of guava juice during storage at 4 °C. After treatment at a pressure of 600 MPa and 25 °C for 15 min, the product exhibited no change in AA content as compared with fresh samples. The authors concluded that guava juice treated at 600 MPa and 25 °C for 15 min retained good quality similar to the freshly extracted juice after storage at 4 °C for 40 days. Taoukis *et al.*, 1998 observed that at elevated temperatures, pressure treatment could degrade

Table 2: HPP effect on nutritional quality attributes of fruit juices

Products	Treatment parameters	Storage conditions	Quality changes	Sources
Blueberry juice	200 MPa, 15 min	Tested right After treatment	Total phenolic and Anthocyanin content increased, whereas no changes in antioxidant capacity, pH, °Brix and Colors	Barba *et al.*, 2013 [8]
Blueberry juice	400-600 MPa, 15 min	Tested right After treatment	Total phenolic and Anthocyanin content increased; no changes in pH, °Brix and Colors; but antioxidant capacity decreased	Barba *et al.*, 2013 [8]
Blood orange juice	400-600 MPa, 15 min	4°C for 10 days	93.4% retention rate of Anthocyanin; 85% retention rate of ascorbic acid	Torres *et al.*, 2011 [96]

vitamin C to a large extent for long treatment time, e.g., pressurization up to 600 MPa at 75 °C for 40 min resulting in 70% and 50% losses of vitamin C, respectively, in pineapple and grapefruit juices. At constant pressure, increasing temperature enhanced the vitamin C degradation, for example loss 20–25% at 40 °C; 45–50% at 60 °C and 60–70% at 75 °C at 600 MPa for 40 min in pineapple juice (Table 2).

10.4 Effect of high pressure processing on viscosity of fruit juices

Fruit juices are composed of an insoluble phase (the pulp) dispersed in a viscous solution which is named serum. The dispersed phase, or pulp, includes fruit tissue cells and their fragments, cell walls and insoluble polymer clusters and chains. The serum is an aqueous solution of soluble polysaccharides, sugars, salts and acids. The fruit juice rheological properties are thus defined by the interactions within each phase and between them. The effect of High Pressure Processing on the rheological properties of fruit juices will thus be a function of the balance between the structural changes in the pulp and serum. Because of this, effects of processing on the serum phase are important for a better understand of the effect of High Pressure Processing on the juice rheological properties. (National Advisory Committee on Microbiological Criteria for Foods, 2006, Augusto *et al.*, 2012, Rastogi *et al.* 2007) [60, 4, 78].

High Pressure treatment can affect the rheological properties of fruit juices. The observed effects are dependent on the conditions of the High Pressure process and the type of fruit. Ahmed *et al.*, (2005) reported that the viscosity of mango juice increased after High Pressure treatments at 100 or 200 MPa (20°C/15 or 30 min), while a reduction in viscosity was observed after High Pressure treatments at 300 and 400 MPa (20°C/15 or 30 min). A shelf-life study on navel orange juice (Polydera *et al.*, 2005) [72] showed that (i) pressure treatment (600 MPa/40°C/4 min) resulted in a higher viscosity than thermal treatment (80 °C/60 s) and (ii) a limited cloud loss and a small decrease in the viscosity of High Pressure-treated juice were observed during storage (0, 5, 10, 15 or 30 °C for 64 days) even at an elevated storage temperature (30 °C).

11. Conclusions and Future Trends

Current knowledge indicates that in general high temperature treatments can affect levels of bioactive compounds in Fruit juices. The mechanism by which bioactive compounds degrade are numerous, complex and perplexing, sometimes unknown. Ensuring food safety and at the same time meeting the demand for nutritious foods (bioactive compound retention), has resulted in increased interest in non-thermal preservation techniques. The use of novel non-thermal processing is well known, several novel and interesting applications for improving the technological properties and the bioactivity of juices have emerged during the past few years. High pressure processing is a promising preservation method of fruit juices. The sensory properties of many High Pressure-treated fruit juices are superior to those of juices preserved in the traditional way by heat treatment. Application of different natural antimicrobials of animal, plant, and microbial origins directly or indirectly added to fruit juices effectively reduce or inhibit pathogenic and spoilage microorganisms. Thus they also represent good alternative of thermal processing of fruit juices. In future, the combination of non-thermal methods and natural antimicrobial compounds would be new trend of preservation of fruit juices that improve the microbiological quality while having the lowest impacts on the organoleptic properties.

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