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High Pressure Processing of Fruits and Vegetables: A Review

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ABSTRACT

Fruits and vegetables are considered as protective foods and received importance in healthy diet plan. Postharvest loss in quality as well as quantity of fruits and vegetables is huge due to seasonal production, high perishability, shorter shelf life and preservation through processing is one of the best methods to minimise the loss. Thermal methods are more popular and these traditional methods of fruit and vegetable preservation often affect the quality of final products in terms of color, taste, flavor and nutritional qualities. Demand for fruit and vegetable products with 'fresh like' qualities are increasing and there is a shift of thermal methods of processing to non-thermal methods to improve the quality of processed products. Several non-thermal methods of processing are developed in order to meet the consumer demand of which high pressure processing has proven to be extremely valuable for fruit and vegetable products. It is an emerging technology in juice and beverage sector which allow fruit and vegetable juices as well as smoothies to store safely for a longer time with fresh taste while preserving its nutritional quality.

Key words: Enzyme inactivation, Fruit products, High pressure processing, Sensory qualities.

India is the second largest producer of fruits and vegetables in the world, next to China with a production of 98.57 MT fruits and 185.88 MT of vegetables (National Horticulture Board, 2018). Despite the higher production, approximately 30% of the fresh produce goes waste due to the high perishability and poor shelf life of fruits and vegetables. Adoption of suitable processing method could improve the availability of fruits and vegetables and reduce the postharvest losses. At present, thermal methods that depends on heat treatment are the most common method of food processing and preservation. However, in thermal methods of processing, large amount of energy is being transferred to the food product which can trigger unwanted reactions leading to undesirable changes in the sensory and nutritional qualities of food (Tiwari *et al.* 2009). Fruit and vegetable products which have the quality, texture, flavour and appearance as that of fresh produce are needed by the consumers and the demand for 'fresh like' products are increasing and there is a shift of thermal methods of processing to non-thermal methods to improve the quality of fruit and vegetable products in terms of appearance, taste, texture and nutritional properties. Among the non-thermal processing methods, high pressure processing and irradiation are of great interest nowadays but irradiation is not well accepted in the market due to the misplaced fear of induced radioactivity. High Pressure Processing (HPP) of food, however, is generating interest as a potential method for producing products with natural qualities with better nutrition (Bansal *et al.* 2015). To ameliorate the undesirable thermal effects in processed products, many non-thermal processing methods have been developed *viz.,* high pressure treatment, pulsed electric fields, ionization radiation and ultra-sonication (Sonaliben *et al.* 2017) of which HPP is the leading commercial technology.

High Pressure Processing

High Pressure Processing (HPP) is the technology of applying high hydrostatic pressure to materials by compressing the surrounding water and transmitting pressure throughout the product uniformly and rapidly (Hayashi *et al*. 1989) and is based on two basic principles; Le Chatelier's and Isostatic principle or Pascal's Law. This implies that all atoms and molecules in the food are subjected to the same pressure at exactly the same time, unlike heat processing where temperature gradients are established and the high pressure help in sterilisation of food while maintaining its nutritional quality (Elamin *et al.*, 2015). High Pressure Processing (HPP), also known as High Hydrostatic Pressure (HHP) or Ultra High Processing (UHP) is a relatively new, non-thermal food processing method that subjects food (liquid or solid) to high hydrostatic pressures at or above 100 MPa (Banerjee and Verma, 2015).

HPP in fruits and vegetables

High Pressure Processing is used in various fruits and vegetable processing industries for both microbial and enzyme inactivation, extending the shelf life while maintaining the sensory as well as nutritional properties of the food product (Gopal *et al.* 2017). Thus, safety and quality of processed fruit and vegetable products can be ensured through HPP. Some of the important findings in this area are summarized as below.

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High pressure processing of fruit products

Product	Conditions	Salient findings	References
Orange juice	500 MPa for 1.5 minutes	Storage up to 16 weeks under refrigeration with increased flavour retention.	Parish, 1998
	400 MPa for 10 minutes	Acceptable quality during storage for 150 days at room temperature.	Strolham *et al*., 2000
	500 or 800 MPa for 5 minutes	Storage up to 21 days at 4°C.	Fernandez *et al*., 2001
	600 MPa for 4 minutes at 40°C	Low ascorbic acid degradation and better retention of the antioxidant activity.	Polydera *et al*., 2004
	550 MPa for 70s at 18°C	45% increase in flavanoid content.	Vierira *et al*., 2018
Lemon juice	450 MPa for 2, 5 and 10 minutes	No fungus growth and no effect on physicochemical properties.	Donsi *et al*., 1998
Guava puree	600 MPa at 25°C for 15 minutes	Storage up to 40 days at 4°C and no change in colour and ascorbic acid.	Gow and Hsin, 1996
Apple juice	600 MPa for 3 minutes	High pressure treated juice retained colour better than thermal treated juice.	Yi *et al.* 2017
Raspberry puree	200-800 MPa,15 minutes, 18-22°C	Highest stability of anthocyanin and increased shelf life under 200 and 800 MPa when stored at 4°C.	Winai *et al*., 2005
Litchi based beverage	500 MPa at 70°C for 20 minutes	pH and total soluble solids remain unaltered with better taste and sensory qualities.	Jayachandran *et al*., 2015
Strawberry puree	400-600 MPa at 20°C for 1.5 minutes	Shelf life of the product was 49 days when processed at 500 or 600 MPa and microbially safe.	Aabya *et al*., 2018
Coconut water	593 MPa for 3 minutes	Retained nutritional quality for 120 days with no off odours and taste as fresh coconut water.	Raghubeer *et al.,* 2020

The packaging material for HPP products should be flexible, able to withstand pressure and maintain the integrity. Polyethylene, polyethylene terephthalate, polypropylene, ethylene-vinyl alcohol, polyamide and nylon films are some of the packaging materials currently used in industrial food processing by high pressure treatments. Vacuum packed products in flexible packages are ideal for HPP, particularly if the packaging could be compressed by about 15% with no structural damage and should return to its original shape upon pressure release (Ayvaz *et al*., 2012). According to Tan *et al*. (2019), high pressure processed durian pulp (500 MPa for 5 minutes) packed in nylon and skin film packing retained the nutritional and organoleptic properties throughout the 56 days storage period.

HPP in enzyme inactivation

Enzyme inactivation is an important criterion for the acceptability of processed products. Different factors such as type of food, origin of enzyme, treatment duration, initial pH and presence of certain additives are the key factors that determines the efficiency and validity of HPP. There exists a minimum pressure below which no or little enzyme inactivation occurs and when pressure exceeds this value, enzyme inactivation increases and completed and this pressure inactivation range is strongly dependent on the type of enzyme, medium composition and temperature (Balny and Masson, 1993). In intact tissues, enzymes and substrate are often separated by compartmentalization, which is being destroyed upon application of pressure due to pressure induced decompartmentalization (Jolibert *et al.* 1994). High pressure mainly affects the tertiary and quaternary structure of enzymes. Oligomeric enzymes are dissociated into individual subunits even at low pressures of 150-200 MPa (Knudsen *et al.*, 2004). One of the main applications of HPP in food technology is to use it as a preservation method to inactivate enzymes in the food products while preserving vitamins, pigments and flavor components (Heinz and Buckow, 2009). HPP can only break non-covalent hydrogen bonds and does not have the ability to break peptide bonds in enzyme (Lopes and Paz, 2010). Chakraborty *et al.* (2014) reported that the primary structure of enzyme remains unaffected by the application of high pressure, as it does not disrupt the covalent bonds. High pressure causes the structural changes in enzyme as weak hydrogen bonds of enzyme are affected, secondary and tertiary structures rupture at high pressure of >600 MPa because of the disruption of electrostatic and hydrophobic interaction (Zhang *et al.* 2016). The pressure stability of an enzyme/protein is strongly dependent on the type of enzyme/ protein, pH, medium composition and temperature, among other conditions (Li *et al.* 2017). According to Toledo *et al.* (2018), HPP has little effect in physicochemical and nutritional properties since high pressure affects only non-covalent bonds such as hydrogen, ionic and hydrophobic bonds. However, high pressure processing can cause unfolding of protein chains and partial or complete protein denaturation which makes it an effective method reducing the activity of food quality related enzymes such as oxidases.

Tsevdou *et al.* (2019) reported that enzyme inactivation by HPP involves a series of events like formation or disruption of numerous interactions, changes in the native structure of enzymes by folding or unfolding *etc*. Pressure induced enzyme inactivation is also due to the pressure induced changes in substrate-enzyme interactions. The effect of high pressure on food endogenous enzymes is linked to a series of food quality attributes.

Pectin Methyl Esterase

Pectin Methyl Esterase (PME) is the major enzyme responsible for cloud destabilization of (orange) juices and consistency loss of (tomato) products and its inactivation is necessary (Hendrickx *et al.* 1998). Commercially, orange juices and tomato products are heat pasteurized to inactivate PME and to prolong the shelf life but thermal method deteriorates sensory and nutritional qualities. Ogawa *et al*. (1990) reported that HPP of 600 MPa can irreversibly inactivate orange PME, which does not reactivate during storage. Basak and Ramaswamy (1996) observed that inactivation of PME in orange juice was dependent on pressure level and holding time in HPP. Bermúdez-Aguirre *et al.* (2011) reported partial inactivation of PME enzyme in mango nectar during HPP and Chakraborty *et al.* (2014) reported PME is baroresistant in several fruit products. Kaushik *et al.* (2016) studied the effect of HPP on quality of mango pulp and observed that HPP decreased the enzymatic activity up to 60% at 600 MPa, 52°C for 10 minutes. Fernandez *et al*. (2018) studied HPP of mixed fruit and vegetable smoothie and reported 627.5 MPa at 20°C for 6.4 minutes as optimal treatment with 85% reduction in PME activity. Chakraborty *et al.* (2019) observed 15% to 67% PME inactivation in pineapple puree at 600 MPa/70°C and it increased with the temperature and pressure. According to Fernandez *et al.* (2020), PME inactivation of 70.7% was observed for HPP vegetable smoothie at 630 MPa for a holding time of 6 minutes.

Peroxidase

In vegetables, peroxidase induces negative flavour changes during storage and Quaglia *et al*. (1996) reported that HPP decreased the peroxidase activity in green beans at 900 MPa for 10 minutes. Cano *et al*. (1997) confirmed the reduction of peroxidise activity (25%) in strawberry puree at 230 MPa, 43°C for 15 minutes and 50% inactivation at 400 MPa, 32°C for 15 minutes in orange juice. Garcia *et al*. (2004) reported 11 to 35% inactivation of peroxidase in strawberries for HPP at 600 and 800 MPa for 15 minutes. Kaushik *et al.* (2016) reported a reduction of 67% of peroxidase activity in mango pulp subjected to HPP at 400 to 600 MPa for 5 to 15 minutes at 40 to 60°C. Chauhan *et al.* (2017) reported complete inactivation of peroxidase enzyme in sugarcane juice at 600MPa for 8 minutes at 60°C. According to Fernandez *et al*. (2018), HPP of 627.5 MPa for 6.4 minutes was the optimal combination for maximum peroxidase inactivation (45%) of mixed fruit and vegetable smoothie. Stinco *et al.* (2019) investigated HPP of cloudy carrot juice and observed the highest inactivation of peroxidase (31%) with 600 MPa and 300 MPa applied in three cycles.

Polyphenol Oxidase

Polyphenol Oxidase (PPO) is responsible for the enzymatic browning of fruits and vegetables thus resulting in colour and flavour loss and HPP can be used as an alternative to high temperature for the irreversible inactivation of PPO. Gomes and Ledward, (1996) studied the optimum pressure for PPO inactivation of different fruits and vegetables and found that mushroom and potato are pressure stable and require high pressures of 800-900 MPa for inactivation whereas apricot, strawberry and grape PPO got inactivated at 100, 400 and 600 MPa respectively. Strawberry puree with 60% reduction in PPO activity was obtained after 285 MPa treatment for 15 minutes at room temperature (Cano *et al*. 1997). Castellari *et al.* (1997) demonstrated that for complete inactivation of grape PPO, HPP treatments in combination with a mild thermal treatment (40-50°C) can be adopted. Rastogi *et al.* (1999) studied HPP combined with heat treatment in red grape juice for PPO inactivation and reported the lowest PPO activities at 60°C, 600 MPa.

Garcia *et al*. (2004) reported 29% PPO inactivation when red raspberries were subjected to 800 MPa for 15 minutes and in strawberries, PPO activity reduced with either 600 MPa for 15 minutes or 800 MPa for 10 minutes. Jacobo-Velázquez and Hernández-Brenes (2010) observed a reduction of 50% PPO activity in HPP (600 MPa/3 minutes) avocado paste stored for 5 days at 4°C. Keenan *et al*. (2012) observed significant increase in PPO activity during initial period of refrigerated storage for fruit smoothie (apple, strawberry, banana and orange) in both control and treated samples followed by a reduction in enzyme activity of HPP samples. PPO activity in fresh cut peaches were partially inhibited at 500 MPa pressure for a holding time of 5 minutes (Denoya *et al.* 2015). According to Kaushik *et al.* (2016), 63% PPO inactivation was observed in HPP mango pulp at 600 MPa for 10 minutes at 52°C. Chauhan *et al*. (2017) studied HPP of sugarcane juice and observed complete inactivation of PPO at 600MPa for 8 minutes at 60°C. Aabya *et al.* (2018) studied the effects of HPP and heat treatment on PPO activity of strawberry purée and juice and observed increased PPO activity during storage of the products. Fernandez *et al*. (2018) investigated HPP of mixed fruit and vegetable smoothie and reported optimal process pressure of 627.5 MPa for 6.4 minutes with 10% reduction of PPO activity. Sreedevi *et al.* (2019) conducted HPP of sugarcane juice and recorded 98% PPO inactivation at 600MPa for 25 minutes at 60°C. PPO inactivation of 57% was achieved when cloudy carrot juice was subjected to HPP at 600 MPa (Stinco *et al.* 2019). Tsikrika *et al.* (2019) investigated HPP of Irish potato cultivars at 600 MPa for 3 minutes and reported lower PPO activity and higher total phenolic content in all HPP treated samples in vacuum sealed polyethylene/ polyamide pouches. High pressure processed vegetable

smoothie showed a reduction in PPO activity of 16.7% at 630 MPa for 6 minutes (Fernandez *et al.* 2020).

HPP in microbial inactivation

Microbial inactivation is one of the main tasks for the application of HPP technology. Certes in 1883 was the first in history to relate the effect of high hydrostatic pressure on microorganisms (Knorr, 1995). In general, vegetative cells are inactivated at lower pressure of around 400-600 MPa, while more resistant bacterial spores can survive at high pressures. Application of HPP cause irreversible structural changes of the membrane proteins and other macromolecules leading to cell membrane destruction of microbes. Bacterial spores require more extreme conditions of pressure and temperature and longer treatment time to get inactivated unless they are in germinated state (Cheftel, 1995). Pressure at a moderate level induce spore germination and this has been the basis for the principle behind inactivation of bacteria where spores are induced to germinate in the first step and inactivated in the second step by a combination of moderate heat and pressure (Raso and Barbosa-Canovas, 2003). The first domain of pressure increase (from 0.1-600 MPa and 30-50°C) result in pressure induced spore germination and the higher pressure lead to spore inactivation (Reineke *et al.* 2013). HPP has the potential to produce microbiologically safe food and can alter the functional properties of proteins, polysaccharides and biochemical reactions without significantly affecting the nutritional and sensory properties of food (Chopde *et al.* 2014). Dhineshkumar *et al.* (2016) reported that a pressure range between 100 and 1200 MPa is effective for inactivation of food borne pathogens. According to Raghubeer *et al.* (2020), HPP of coconut water at 593 MPa for 3 minutes was effective in eliminating *E. coli*, *Salmonella* and *L. monocytogenes* compared to untreated samples.

HPP on organoleptic qualities

Organoleptic qualities are the aspects of food that an individual experiences by senses and colour, taste, texture and flavour are important quality characteristics as well as major factors affecting sensory perception and consumer acceptance of processed fruit and vegetable products. During HPP, different pressure and temperature combinations are used to achieve desired effects on colour, texture and flavour of foods while preserving the nutritional and delicate sensory properties since high pressure does not break covalent bonds of low molecular mass compounds such as colour and flavour compounds.

Colour

Colour is regarded as a major food quality attribute in determining product acceptability. Major colour contributing groups are chlorophyll, carotenoids and anthocyanins. With regard to green colour, a common change in processed green plants is the degradation of chlorophyll (green colour) to pheophytins (grey-brown colour) which is highly associated with reduction in product quality. At room temperature HPP, chlorophylls exhibited stability but on elevating pressure from 200 to 800 MPa at temperature higher than 50°C resulted in the degradation of chlorophyll a and chlorophyll b of broccoli by 19.4% and 68.4% respectively (Loey *et al*. 1998). High pressure treatment at ambient and moderate temperatures resulted in limited colour change of green vegetables or became more intense. Green beans after HPP at 500 MPa and ambient temperature for 1 minute showed better colour compared to untreated green beans (Krebbers *et al*. 2002a). Matser *et al.* (2004) studied HPP of spinach and tomato puree and reported that colour of HPP spinach and tomato puree was better as compared to heat sterilised samples, chlorophyll degradation was observed at elevated temperatures even for a short exposure time. Better colour in HPP samples might be due to the cell disruption during high pressure treatment resulting in the leakage of chlorophyll into the intercellular space yielding a more intense bright green colour on the vegetable surface was reported by Oey *et al.* (2008).

Carotenoids are important for the orange-yellow and red appearance of fruits and vegetables. Jennifer *et al*. (2007) studied pressure treatment of carrot, green beans and broccoli at 400 and 600 MPa and reported that there was no effect of HPP on levels of carotenoids. Lutein and β-carotene the major carotenoids in broccoli were stable under HPP and the colour of tomato puree remained unchanged after HPP up to 700 MPa at 65°C even for 1 hour (Rodrigo *et al*. 2007). In watermelon juice, lycopene level was unchanged after moderate pressure treatment and increased only with HPP between 600 and 900 MPa at room temperature for 20 to 50 minutes (Zhang *et al.* 2011). According to Denoya *et al.* (2015), HPP of fresh cut peaches at 500 MPa for 5 minutes under vacuum packaging had a synergestic effect on colour preservation for 21 days. Barba *et al.* (2017) reported increased extraction of carotenoids in high pressure processed vegetables. Stinco *et al.* (2019) assessed the impact of HPP on the carotenoid profile of cloudy carrot juice and observed that 300 MPa in three cycles caused the highest carotenoids degradation (41%) whereas the lowest degradation (26%) was achieved at 600 MPa. Pressure Assisted Thermal Sterilization did not influence the carotenoid content of pumpkin, butternut squash, beetroot and purple potato puree after pressure treatment (Al-Ghamdi *et al.,* 2020). Ancos *et al.* (2020) examined the effect of HPP as a pretreatment on whole peeled 'Navel' and red-fleshed 'Cara Cara' sweet oranges before juicing and observed that HPP at 400 MPa/ 40°C/1 minute produced an orange juice with higher carotenoid concentration than in 200 MPa processed orange juice.

Anthocyanins are water soluble vacuolar flavonoid pigments responsible for the red to blue colour of fruits and vegetables. Garcia *et al*. (2004) observed that pelargonidin-3-glucoside and pelargonidin-3-rutinoside, the major anthocyanins in red raspberry and strawberry was stable during HPP at 800 MPa, 18-22°C for 15 minutes. Kouniaki

et al. (2004) studied the impact of HPP on the important anthocyanins in blackcurrants and observed that high pressure at 600 MPa gave the best stability for anthocyanins in fruits stored at 5°C. The anthocyanin levels of HPP blackberry puree were higher than fresh samples (Patras *et al*. 2009). George *et al.* (2016) studied high pressure assisted infusion of bioactive compounds in apple slices and reported better infusion of anthocyanin at 250 MPa than at 0.1 MPa. Aabya *et al.* (2018) studied HPP and heat treatment (85°C for 2 minutes) of strawberry purée and juice and recorded 57 and 67% anthocyanin retention in HPP and heat treated purée respectively after 35 days of storage at 6°C. According to Saikaew *et al*. (2018), anthocyanin content of HPP purple waxy corn was higher at 700 MPa than 550 MPa for the treatment time of 30 to 45 minutes. You *et al.* (2018) observed colour changes of HPP mulberry juice (400 MPa/5 minutes) for 30/days of storage at 4°C and found the highest retention rate of 84.70%, 80.20% and 98.61% for total anthocyanin, cyanidin-3-glucoside and cyanidin-3-rutinoside respectively. Anthocyanin content of pumpkin, butternut squash, pea, beetroot and purple potato puree were studied with preheating at 98°C for 5 minutes and pressurizing at 600 MPa at 90°C for 5 minutes, recorded a decrease and anthocyanins are found as pressure sensitive (Al-Ghamdi *et al.* 2020).

Texture

Different pressure and temperature combinations can be used to activate or inactivate some specific pectinase during processing to create textures, which cannot be formed by thermal processing. Moreover, the use of HPP can be combined with pretreatments such as infusion of exogenous pectinases (Duvetter *et al*. 2005) or soaking in calcium chloride solutions (Sila *et al*. 2006) which can result in increased firmness of the processed fruit and vegetable products. Textural changes in processed prodcucts can be related to transformations in cell wall polymers due to enzymatic and non-enzymatic reactions (Sila *et al*. 2007).

Basak and Ramaswamy (1998) studied the effect of HPP on the firmness of apple, pear, orange, pineapple, carrot, celery, green pepper and red pepper and noticed tissue softening at pressure above 200 MPa. Tangwongchai *et al.* (2000) compared the pressure sensitivity of different fruits and observed that pear was the most pressure sensitive followed by apple, pineapple and orange at 100 MPa, while at 200 MPa, apple was more sensitive than pear which revealed that the effects of HPP are dependent on process conditions and type of fruit or vegetable. Reduction in viscosity of processed products might be due to the degradation of pectic substances by endogenous enzymes such as pectin methyl esterase and polygalacturonase (Creiler *et al.* 2001). Plaza *et al.* (2003) observed decreased viscosity of tomato puree at pressures less than 400 MPa and increased at higher pressure of 500 MPa combined with temperatures up to 60°C. Ahmed *et al*. (2005) reported that viscosity of mango pulp increased after HPP at 100 or 200 MPa at 20°C for 15 or 30 minutes, while a reduction in viscosity was observed after the high pressure treatments. Improved textural quality was observed for carrot and spinach at 100 MPa for 20 minutes (Jung *et al*. 2012). According to Denoya *et al.* (2015), texture of fresh cut peaches were preserved for 21 days at 10°C by HPP at 500 MPa for 5 minutes. Paciulli *et al.* (2016) applied HPP of 650 MPa on beetroot slices and observed that textural properties *viz*., hardness and chewiness were better retained in HPP samples than thermally treated samples. According to Scheidt and Silva (2018), hardness was not affected by the processing time and remain same just after HPP and one week storage at 3°C for blueberries at 200 and 600 MPa. The effect of HPP on carrot texture was investigated and found that carrot hardness and chewiness at 400MPa resulted a loss of 71.0%, 73.8% respectively with no further loss with increase in pressure (Sun *et al.* 2019). Hu *et al.* (2020) studied HPP induced textural changes of fresh-cut pumpkins and found that hardness decreased with increase in pressure. Tao *et al.* (2020) reported 200MPa as optimal pressure for “Laba” garlic for retaining the textural quality which was mainly attributed to the compacted cells and the increased Ca2+-cross linked cell-cell adhesion.

Flavour

Flavour is the sensory impression of a food that is determined mainly by the chemical senses of taste and smell. Any changes in the compounds responsible for the sourness, sweetness, bitterness or odour of fruits and vegetables may result in changes in their flavour. The fresh flavour of fruits and vegetables is not altered by HPP, since the structure of small molecular flavour compounds is not affected by high pressure.

The typical off-flavour of heat treated mandarin juice was not detected in HPP juice with 400 MPa at ambient temperature for 10 minutes (Takahashi *et al.* 1993). Lambert *et al*. (1999) observed better flavour retention of HPP strawberry puree in comparison with heat-treated (80°C for 5 minutes) puree. Krebbers *et al.* (2002b) studied flavour changes during HPP of basil and observed more intense flavour with high pressure than heat sterilized, frozen or dried basil even after two months of storage at 20°C. Keenan *et al*. (2012) reported that no difference in the flavour profile such as limonene or trans-2-hexanal of thermally and HPP treated smoothies containing apple, orange, banana and strawberry. Fruit flavour was maintained in mixed fruit smoothies pressurized at 350 and 450 MPa and prevented the development of off-flavours (Hurtado *et al.* 2015). Scheidt and Silva (2018) reported that HPP of blueberries at 200 and 600 MPa at 3°C had low impact in changing the original fruit flavour and retained flavour profiles throughout the storage period. Tao *et al.* (2020) compared the effects of High Pressure Carbon Dioxide (HPCD) and HPP on flavour profile of “Laba” garlic and reported that flavour profile could be modified HHP or HPCD as alliinase activity was inactivated rapidly with the increase in pressure.

Effect on antioxidant activity

Antioxidant activity is considered as an important parameter for assessing health contribution of the product which usually decrease with thermal processing. Jennifer *et al*. (2007) reported that HPP broccoli had no effect on antioxidant activity, for carrots there was a modest reduction at 400 MPa, whereas for green beans, antioxidant activity increased by pressure treatment at 400 and 600 MPa for 2 minutes. According to Patras *et al*. (2009), levels of phenols in HPP strawberry and blackberry puree at 600 MPa at 10 to 30°C for 15 minutes was higher as compared to unprocessed puree which resulted in higher antioxidant activity. For HHP (450 MPa) fruit smoothie samples, significant reduction in antioxidant activity and phenolic content were observed when stores under refrigeration for 30 days (Keenan *et al.* 2010). HPP processing (400 MPa, <30°C, 20 minutes) retained more total phenolics and antioxidant activity in *Centella asiatica* L. juices than pasteurised or high-temperature short-term sterilization (Apichartsrangkoon *et al.* 2012). Alvarez-Jubete *et al.* (2014) investigated the effect of HPP on antioxidant activity of white cabbage (*Brassica oleracea* L. var. *capitata alba*) and found that 600 MPa resulted in higher total phenol content and total antioxidant capacity. Hurtado *et al.* (2015) studied HPP at cold temperature as an alternative to thermal pasteurization to obtain multi-fruit smoothies and reported that HPP smoothies had a lower antioxidant activity than the thermally treated smoothies after 48 h of processing. According to Hurtado *et al.* (2017), antioxidant activity of fruit based smoothie remain unaffected after HPP at 350 MPa, 10°C for 5 minutes. Fernandez *et al*. (2018) studied HPP of mixed fruit and vegetable smoothie and reported 27.5 MPa for 6.4 minutes as optimum condition which resulted in 75% increase of antioxidant activity. Saikaew *et al*. (2018) reported that HPP of purple waxy corn decreased the antioxidant activity as the pressure increased from 250 to 550 MPa but the levels recovered at 700 MPa. The influence of HPP on two varieties of Golden Delicious apple was investigated and reported that HPP increased all classes of phenolic compounds in Italian Golden Delicious apple and exhibited higher antioxidant activity than Spanish Golden Delicious apple at optimal process pressure of 600 MPa (Fernández-Jalao *et al.* 2019). Ubeira-Iglesias *et al.* (2019) studied HPP of beetroot juice at 600 MPa, for 3 minutes at room temperature and observed higher retention of antioxidant properties throughout the storage period of 21 days under refrigeration.

CONCLUSION

Fruit and vegetable processing industry is an emerging sector for economic and nutritional security of the country. Nowadays, convenient fruit and vegetable products which are nutritious as well as safe for consumption with natural flavour and taste, free from preservatives are of high demand. Although thermal pasteurization technology remains a core technology in the food industry, it may affect the appearance, flavour and nutritional value of the products and does not necessarily meet the demand of modern society for natural, fresh and aesthetically appealing food. High Pressure Processing offers opportunities to develop processed products with extended shelf life, maintaining the nutritional quality and fresh like organoleptic properties meeting the consumer demand for nutritious, safe and wholesome products with fewer additives. Several researchers have demonstrated diverse use of HPP in fruit and vegetable processing and more research is needed to address the challenges to understand the interaction between high pressure and changes in food constituents and to optimize the process conditions for each product.

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