

High Pressure Processing of Fruits and Vegetable Products: A Review

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Received: 29.04.2017 | Revised: 31.05.2017 | Accepted: 7.06.2017

ABSTRACT

The nasty lifestyle of people in this fast moving world has made the people to think about their health and food. The growing concern about food born diseases and intense use of preservatives and chemicals has made the consumers to shift towards natural and healthy foods such as fruits and vegetables and high quality convenience foods in terms of natural flavor and taste, and which are free from additives and preservatives. This demand has triggered the need for the development of a number of non thermal approaches to food processing, of which high-pressure technology has proven to be very valuable. HPP is a clean non thermal processing technique applied to food materials for inactivating microorganisms and retaining quality at the highest level. HPP is the alternative to heat processing for fruit & vegetable products such as puree, coulis and sauces. It gets a significant shelf life extension, keeping fresh and home-made taste. The high pressure processing of fruit and vegetable products have their own advantages and disadvantages therefore, this paper reviews information on various fruit and vegetables products processed by HPP and its effect on various components, physical properties and microbial characteristics.

Key words: Lifestyle, HPP, Diseases, Microbial characteristics.

INTRODUCTION

The growing concerns regarding healthy eating habits, consumer demand has increased for fresh fruits and vegetables that are free from chemical residues. The high nutritional and medicinal properties of fruits and vegetables has motivated for development of array of processed fruit and vegetable products which has lead for improvement of existing

technologies and invention of novel and sustainable technologies²³.The processing industry is offering a growing range of ready-to eat fresh-cut fruits and vegetables, fruit juices, jams, purees etc but these products are very sensitive to contamination and very limited, due to their shelf-life, colour and texture changes, and off-flavour and off-odour development²¹.

Cite this article: Gopal, K.R., Kalla, A.M. and Srikanth, K., High Pressure Processing of Fruits and Vegetable Products: A Review, *Int. J. Pure App. Biosci.* 5(5): 680-692 (2017). doi: <http://dx.doi.org/10.18782/2320-7051.2930>

The food safety is a major concern for any food industry, whether it is a preserving of fresh fruits and vegetables after harvesting where reducing of metabolic activity is a major concern or maintaining the quality of processed fruit and vegetable products. There are many conventional methods currently applied in food industry like thermal processing, cooling and controlled atmosphere for different purposes in fruit and vegetable quality management. The ultra violet and heat treatment have shown some inherent heterogeneity problems resulting in relatively poor commercial application.

The application of a physical stress to some harvested produce has been found to promote their natural disease resistance and lead to an increase in resistance against future infection⁵⁵. In some cases, an increase in the quality attributes of the fruit or vegetable has been observed¹³. Physical treatment, such as pressure treatment, is one of the techniques that can meet the requirements of consumer for high quality foods that are microbiologically safe with an extended shelf-life²⁴. Pressure treatment consists of applying to the commodity pressure outside the range of atmospheric conditions. Unlike heat processing, where temperature gradients are established, pressure treatment offers homogeneity as it acts instantaneously and uniformly around each single produce or throughout an entire mass of food, independently of its size, shape or composition⁴¹. However, considering the large range of pressures that can be applied to produce, pressure treatments need to be categorized into two main categories; low and high pressure treatment. Low pressure (0–1 MPa) treatment can be hypobaric or hyperbaric and is applied to fresh produce, while high pressure (above 100 MPa) treatment is generally applied to processed food. The hyperbaric treatments (0.1 to 1.0 MPa) differ from high-pressure treatment; the latter consists of subjecting food to pressures between 100 and 1200 MPa²³. The cell structure of fresh fruits and vegetables cannot

withstand these pressures causing irreversible damage². In between these categories, the pressure treatment might be too high to treat pressure-sensitive produce, such as fresh horticultural crops, without causing irreversible damage. It is also generally too low to have a significant effect on microorganisms and enzyme activity. The abnormal ripening was most evident in fruit subjected to pressures ≥ 100 MPa, which led to browning and softening, rendering treated fruit commercially unacceptable. The HPP may be utilized for processed but not fresh fruit⁵.

High Pressure Processing

The food product to be treated at high pressure is packaged in a flexible container and placed inside a pressure vessel submerged in liquid medium (mostly water), which transmits the pressure. The effect of HPP are uniform and nearly instantaneous throughout the food and, thus, independent of food geometry and equipment size. Once the desired pressure is achieved, the pump or piston is stopped, the valves are closed and the pressure can be maintained without further energy input. After the required hold time has elapsed, the system is depressurised, the vessel opened and the product taken out. During pressurisation, the temperature of the product increases by about 3°C/100 MPa due to compression heat. The total time for pressurisation, holding and depressurisation is termed the 'cycle time' or "pulse"².

High-pressure treatment (HPT) is a nonchemical treatment that has been reported to inactivate microorganisms through membrane disruption²⁷. It preserves nutritional value with minimal effect on product quality and sensory properties of fruit and vegetable products, since lower molecule weight food compounds, such as flavouring agents, pigments and some vitamins are not altered, because covalent bonds are not affected by pressure³¹. HPP mainly affects noncovalent bonds²⁵, in contrast to high temperature treatments which can destroy covalent bonds in vitamins, amino acids, and other substances related to freshness.

The HPP application in fruit and vegetable products

HPP is used in various fruits and vegetable processing industries for the inactivation of microorganisms and enzymes, for extending the shelf life and maintaining better organoleptic, sensory, and nutritional

properties. Several commercial products, including fruit juices, i.e. mandarin, grapefruit, apple, orange, carrot juices and broccoli-apple juice mixture treated by HHP are currently available on market^{1,6}. Some of the important finding in this area has been summarized in Table 1 & 2.

Table 1: High pressure processing of fruit products

Product	Conditions	Salient results	Refernces
<i>Orange juice</i>	350 MPa, 1 min at 30°C	Good quality juice with more than 2 months' shelf life under refrigeration condition.	Donsi, Ferrari, and Matteo ¹⁸
	600 MPa for 4 min at 40°C	The rate of degradation of ascorbic acid was lower for orange juice treated with high pressure, which led to a better retention of the antioxidative activity when compared with juice pasteurized in a conventional way using heat.	Polydera, Stoforos and Taoukis ⁴³
<i>Lemon juice</i>	450 MPa, for 2, 5 or 10 min	No fungus growth was detected in the pressure treated sample, whereas the control sample was spoiled by yeast and filamentous fungi after 10 days. Little effects of HPP on the constituents and physicochemical properties.	Donsi, Ferrari, Matteo, and Bruno ¹⁹
<i>Guava puree</i>	600 MPa, 25°C for 15 min	Storage up to 40 days at 4°C without any change in any change in color and pectin cloud and with no loss of ascorbic acid. No change in water soluble, oxalate soluble and alkali soluble pectin with original flavor distribution and viscosity.	Gow and Hsin ²²
avocado paste	600 MPa for 3 minutes and stored for 45 days at 4°C.	Reported a decrease in polyphenoloxidase (PPO) and lipoxigenase (LOX) in avocado paste. Lactic acid bacteria counts were very low during storage. pH was consistently declining during the first 20 days of storage.	Jacobo-Velázquez and Hernández-Brenes ³⁰
<i>Apple juice</i>	400 MPa, 10 min	Compared the sensory quality during storage of apple juice subjected to high pressure with that preserved by freezing (-17°C) or pasteurization (80°C, 20 min). The best samples were frozen juice, followed by pressurized, and then by pasteurized, juice with much substantial difference in aroma.	Novotna, Valentova, Strohal, Kyhos, Landfeld, and Houska ³⁸
<i>Fresh cut pineapple</i>	340 MPa for 15 min	Extended the shelf life, and decimal reductions of surviving bacteria were 3.0, 3.1, and 2.5 at 4°C, 21°C and 38°C, respectively. Pressure treated pineapple pieces had less than 50 cfu/g total plate count as well as yeast and mold counts.	Aleman, Farkas, Torres, Wilhelmsen, and McIntyre ³
<i>Strawberry juice</i>	200–500 MPa	No major changes in strawberry aroma profiles, whereas a pressure of 800 MPa, induced significant changes in the aroma profile and new compounds were induced.	Lambert, Demazeau, Largeteau, and Bouvier ³³
<i>Raspberry puree</i>	200–800 MPa for 15 min, 18–22°C	The impact of high pressure on anthocyanin in raspberry puree was evaluated. The highest stability of the anthocyanin was observed when the puree was pressured under 200 and 800 MPa and stored at 4 °C.	Winai, Paul, and Ioannis ⁶²
<i>Red and white grape</i>	300–800 MPa for 1–5 min	Processing at 500 MPa for 3 min sterilized the white grape must, whereas treatment at 800 MPa for 5 min	Moio, Masi, Pietra, Cacace,

<i>musts</i>		did not fully sterilize red grape must. This is due to higher pressure stability of the natural microflora present in red grape. There were little changes due to high-pressure sterilization on physicochemical properties.	Palmieri, Martino, Carpi, and Dall'Aglio ³⁶
<i>White peach</i>	400 MPa, 20°C, 10 min	Enzymic formation of benzaldehyde, C6 aldehydes, and alcohols by disruption of fruit tissues was observed in high pressure treated fruit and crushed fruit. The increase in benzaldehyde content in high pressure treated fruit during storage was caused by residual activity of beta-glucosidase after the treatment.	Sumitani, Suekane, Nakatani, and Tatsuka ⁵²
<i>Lychee</i>	200–600 MPa for 10 or 20 min at 20–60°C	Pressure treatment caused less loss of visual quality in both fresh and syrup-processed lychee than thermal processing. Pressure of 600 MPa at 60°C for 20 min caused extensive inactivation of POD and PPO in fresh lychee, over 50% and 90%, respectively. In case of the sample processed in syrup, these effects were less significant	Phunchaisri and Apichartsrangkoon ⁴²
<i>Kiwifruit, peaches, pears and melon</i>	400 MPa, 5 or 20°C for 30 min	Melon was the most suitable fruit for high pressure processing; peaches and pears underwent browning, which was prevented by addition of ascorbic acid, and kiwifruit became yellow. Texture of all fruits was acceptable after processing. PPO and POD enzymes could not be inhibited by processing, however, activities were higher at 20°C as compared to 5°C.	Prestamo and Arroyo ⁴⁶
<i>Strawberry jam</i>	400 MPa at room temperature for 5 min	Explained the production of high-pressure processed jam. The mixture of the powdered sugar, pectin, citric acid and freeze concentrated juice were mixed and then degassed and pressurized. The jam was of bright and red color and retained all the original flavor compounds. The texture of the product was similar to conventionally prepared jam.	Watanabe, Arai, Kumeno, and Honma ⁵⁹

Table 2: High pressure processing of vegetable and its products

Product	conditions	Salient results	References
<i>Broccoli</i>	500 MPa for 10 minutes	high pressure processing (500 MPa for 10 minutes) of apple-broccoli juice and noted that pressure inactivates more than 5 logs of the microbial population and preserves the content of sulforaphane, a compound that exhibits anticancer, antidiabetic and antimicrobial properties to broccoli	Houska <i>et al</i> ²⁸ .
<i>Cabbage</i>	500 MPa	HPP processing of white cabbage reduced the proportion of soluble fiber without significantly affecting the total dietary fiber (TDF) content.	Wennberg and Nyman ⁶¹
<i>Carrots</i>	100, 200 and 300 MPa at 20°C	High pressure treatments of carrots resulted in a significant loss of hardness. Increase in pressure levels did not induce greater texture losses. Cell deformation, shape factors, elongation and turgidity loss were also observed.	Araya <i>et al</i> ⁴ .

<i>Tomato puree</i>	700 MPa	Natural flora of the tomato puree was reduced below detectable limits. High pressure resulted in higher reduction in spore counts of meatballs inoculated with <i>Bacillus stearothermophilus</i> spores added to the tomato puree, as compared to conventional sterilization, without significant loss of lycopene.	Krebbers, Matser, Hoogerwerf, Moezelaar, Tomassen, and Berg ³²
<i>Onion</i>	350 MPa, 25°C and 40°C for 30 minutes	significantly reduced the microbial load of fresh onions but did damage onions membrane without inactivating undesirable enzymes which lead to changes in the odor and flavor of fresh onions. Pressures above 100 MPa damaged the cell structure, releasing polyphenoloxidase (PPO) and inducing then browning of the onions. Browning rate increased with increasing pressure.	Butz et al ¹⁰ ,

The Effect of Hp Processing On Different Components and Physical Properties of Fruits and Vegetables and Their Products

The Effect Of Hpp On Phenolic Compounds

Phenolic compounds are healthy substances, therefore amount of phenolic compounds in fruits/fruit juices are important for customers. It has been demonstrated that a diet rich in fruits and vegetables containing various classes of polyphenols (phenolic acids, flavanols, catechin monomers, proanthocyanidins, flavones, flavanones, and anthocyanins) decreases the risk of premature mortality, cardiovascular disorders, advancing age-induced oxidative stress, inflammatory responses and diverse degenerative diseases^{35,49}. Flavonoids are the most common and widely distributed group of plant phenolics. Among them, flavones, flavanols, flavanones, anthocyanins, and isoflavones are particularly common in fruits.

HHP is better than thermal processes on retaining phenolic compounds. HHP treatment at ambient temperature is reported to have minimal effect on the anthocyanins content of various fruits and vegetables. Several authors have reported that the anthocyanins of different liquid foods are stable to HHP treatment at moderate temperatures. Several authors have reported the increased extractability of coloured pigments in food components at extreme pressures results polyphenol content increase.

The authors attribute the increase of the total phenolic content to the release of some antioxidant components such as anthocyanins, amino acids and protein with phenolic hydroxyl group after HHP treatment from solid suspended particles following the high pressure processing³¹. The effect of high pressure on the anthocyanin content of fruit derivatives cannot be generalized, while the composition of the product, the activity of the oxidative enzymes and the processing and operative conditions could compromise the efficiency of the HHP treatment. Enzymes such as polyphenoloxidase, peroxidase and β -glucosidase have been implicated in the degradation of phenolics and anthocyanins⁵⁶.

Anthocyanins

Higher temperature of processing and storage are reported to make anthocyanins unstable. No significant change in anthocyanins of fruits was observed when processed by HPP. HHP effectively retained anthocyanins, phenolic compounds and color of pomegranate juice for treated samples with 350 MPa and 550 MPa at room temperature⁵⁸. Greater retention of HHP samples is found compared to HTST (110°C/8.6s) samples in cloudy pomegranate juice¹⁴. Anthocyanins of blueberry juice samples treated with 600 MPa at 42°C, increased significantly⁶. Significantly higher loss of anthocyanins in HHP-treated cloudy strawberry juices were observed than in HHP treated clear strawberry juices at 4°C storage,

which was possibly due to higher concentrations of oxygen absorbed on pulp particles promoting the degradation of anthocyanins. Moreover, the loss of anthocyanins in both juices at 25°C were significantly higher than at 4°C and only less than 5% anthocyanins were retained in both juices after 6 months of storage at 25°C, which mainly resulted from higher storage temperatures¹¹.

The Effect of Hpp On Colour

HP processing has a limited effect on pigments (e.g. chlorophyll, carotenoids, anthocyanins, etc.) responsible for the colour of fruits and vegetables. HPP is less damaging than thermal processes to low molecular weight food compounds like pigments, as covalent bonds are not affected by pressure⁵⁴. Since HPP can change the colour of diamond, colour change of food materials in a high pressure system is expected¹⁵. However, the colour compounds of HP processed fruits and vegetables, 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.

Numerous studies have been carried out on effect of HPP on colour of various fruits and vegetable product, here are some of quick look on them, Palou *et al*⁴⁰, studied the colour of high pressure treated banana puree and found that treatment preserved the initial colour of the puree. Rodrigo *et al*⁴⁸, reported that maximum increase of 8.8% in *La/b* parameter was found for strawberry juice samples under combined thermal and high pressure treatment (300–700 MPa, 65°C, 60 min). Weemaes *et al*⁶⁰, investigated pressure-temperature degradation kinetics of broccoli juice greenness (both colour and chlorophyll). The pressure and temperature used in the study were 0.1–850 MPa and 30–90°C, respectively. No significant reduction of green colour was observed at pressures of 800 MPa and at temperature ranges of 30–40°C.

Chlorophyll is a green compound found in the leaves and green stems of plants. 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, HP treatment affects their stability for example, a significant reduction in the chlorophyll content of broccoli juice^{8,57}. The temperature dependency of the degradation rate constant of chlorophyll a is higher than that of chlorophyll b. During storage, the green colour of the vegetables HP treated at room temperature turned into a pale yellow colour (decrease in *a** value) probably due to chemical reactions such as oxidation. By comparison, the vegetables pressurized at elevated temperatures, which results in inactivation of some enzymes, showed no further colour change during storage.

Carotenoids are important for the orange-yellow and red appearance of fruits and vegetables. Carotenoids are rather pressure stable. HP treatment increases the extraction yields of carotenes from the plant matrix^{17,20,21}. Butz *et al*⁹, reported the ultra-high pressure treatment of various fruit juices individually and in combination (oranges, apples, peaches, mixed citrus juices, carrots, tomatoes, and frozen raspberries) and found that there were no significant differences in carotenoid content between the pressure-treated and the control samples. The colour of tomato puree remained unchanged after HP treatment (up to 700 MPa) at 65°C even for 1 h⁴⁸. Anthocyanins are other group of colouring compounds, where the effect of HPP on these compounds is discussed above.

The Effect of Hpp On Flavour

Flavour is the sensory impression of a food that is determined mainly by the chemical senses of taste and smell. It is generally assumed that the fresh flavour of fruits and vegetables is not altered by HPP, since the structure of low molecular flavour compounds is not directly affected by high pressure³⁹. Various studies were carried out on the effect of HPP on a variety of flavor compounds of fruits and vegetable products such as hexanal, esters, acids and ketone compounds. Navarro *et al*³⁷, observed that HP processing at 400 MPa (ambient temperature/20 min) more than

doubled the hexanal content of strawberry puree. Porretta *et al*⁴⁵, reported that HP treatment (500, 700 or 900 MPa/room temperature/ 3, 6 or 9 min) of fresh tomato juice resulted in the generation of such a strong rancid taste, that the juice was unsuitable for sensory analysis, n-hexanal was suggested to be responsible for the rancid taste. The concentration of many volatile compounds contributing to fresh strawberry flavour, such as nerolidol, furaneol, linalool and some ester compounds was significantly lower in the strawberry puree processed at 800 MPa (20°C/20 min) than in the unprocessed puree. After cold storage (1 day, 4°C), the concentrations of acids (butanoic acid, 2-methyl-butanoic acid and hexanoic acid) and the ketone compound 2,4,6-heptanetrione of HP treated (200, 400, 600 or 800 MPa/18-22°C/15 min) strawberries were lower than in the untreated strawberries⁶³. The comparison of effects of HHP treatment (600 MPa, 5 min, at ambient temperature) and heat pasteurization (80 °C, 5 min) on volatile composition of raspberry, strawberry and blackcurrant purees measured by 'electronic nose' at 25 °C was conducted and was observed to have better flavor retention of HPP processed purees. Cross validation of the electronic nose data showed that heat treatment changed volatile compounds more than HP processing. Corresponding results were reported for similarly processed raspberry and black currant purees¹⁶. HP processing is a promising preservation method of fruits and vegetables, even though the original fresh sensory properties are not always fully retained. The sensory properties of many HP-treated fruit and vegetable products are still superior to those of products preserved in the traditional way by heat treatment.

The Effect of Hpp On Texture

HP treatment can disturb the cell permeability of fruits and vegetables, which enables movement of water and metabolites in the cell. It causes cell disruption and facilitates the occurrence of enzymatic and non-enzymatic reactions. Texture changes in fruits and

vegetables can be related to transformations in cell wall polymers due to enzymatic and non-enzymatic reactions³⁹. Pectin which is the major component of middle lamella that helps to bind cells together, can be degraded by the successive demethoxylation and depolymerization by pectinmethylesterase (PME) and polygalacturonase (PG) respectively⁵⁰. HP processing affects the organization of the parenchyma cells. The plant cells disintegrate and the intercellular spaces are no longer filled with gas (for example in spinach leaf). The cavity formation occurs and a firm texture and a soaked appearance (e.g. cauliflower) are noticed after HP processing.

Basak and Ramaswamy⁷ studied the effect of HP processing (100-400 MPa/5-60 min/room temperature) on the firmness of different fruits and vegetables such as apple, pear, orange, pineapple, carrot, celery, green pepper and red pepper. The authors observed a rapid firmness loss during compression. During the pressure holding period (30-60 min), the firmness either decreased further or recovered gradually, such as for pear, orange, pineapple, carrot, celery, green pepper and red pepper treated at 100 and 200 MPa. Pectinmethylesterase activity was suggested to be the major reason for the observed increase in firmness. Fruits and vegetables such as apple, pear, orange, pineapple, carrot, celery, green pepper and red pepper experienced softening at pressures above 200 MPa (room temperature/5-60 min)⁷. At 100 MPa, pear was the most pressure sensitive fruit followed by apple, pineapple and orange, while at 200 MPa, apple was more sensitive than pear. Softening under pressure was also observed for cherry tomatoes⁵³.

HP processing also affects the rheological properties of fruit and vegetable products. Ahmed *et al*¹, reported that the viscosity of mango pulp increased after HP treatments at 100 or 200 MPa (20°C/15 or 30 min), while a reduction in viscosity was observed after HP treatments at 300 and 400 MPa (20°C/15 or 30 min). Polydera *et al*⁴⁴, showed that pressure treatment (600 MPa/40°C/4 min) resulted in a

higher viscosity than thermal treatment (80°C/60 s) and a limited cloud loss and a small decrease in the viscosity of HP-treated juice were observed during storage (0, 5, 10, 15 or 30°C for 64 days) even at an elevated storage temperature (30°C). It is suggested that residual PME activity is responsible for the quality loss of orange juice during storage. The different pressure and temperature combinations can be used to activate or inactivate some specific pectinases during processing to create textures, which cannot be formed by thermal processing.

The Effect of Hpp On Enzymes

Enzymes, like other proteins, are stable within a certain pressure temperature domain. Exceeding these limits disturbs the forces stabilizing the three-dimensional protein structure, causing unfolding and denaturation of the molecule, and hence, inactivation⁵⁰. Effects of high pressure on enzymes may be divided in two classes. In the first, comparatively low pressures (100MPa) have been shown to activate some enzymes. This stimulation effect is, however, only observed for monomeric enzymes. Much higher pressures, on the other hand, generally induce enzyme inactivation²⁶.

The enzymes, which pose a problem such as deterioration and unacceptable sensory and textural changes in fruits and vegetable include polygalacturonase (PG), pectate lyase (PL) peroxidase (POD), pectin methylesterase (PME), lipoxygenase (LOX), and polyphenol oxidase (PPO)⁵⁰. The PME catalyzes the demethoxylation of pectin resulting in the formation of demethoxylated pectin molecule which can cross-link with divalent ions like calcium forming supramolecular assemblies and/or gels (firming effect) and act as a substrate for PG depolymerization (softening effect). Pectin methyl esterase is responsible for cloud destabilization of (orange) juices, gelation of concentrates and consistency loss of (tomato) products. The peroxidase in vegetables induces negative flavour changes during storage²⁶.

The combined effect of HPP and thermal treatment is found to be very effect

against inactivation of enzymes. A complete kinetic characterization of pressure and/ or temperature-induced enzyme inactivation for the model enzyme system *Bacillus subtilis* α -amylase has been studied by Ludikhuyze *et al*³⁴. Rastogi *et al*⁴⁷, studied the inactivation effects of high hydrostatic pressure treatment (100-600 MPa) combined with heat treatment (0–60°C) on POD and PPO enzyme, in order to develop high pressure-processed red grape juice having stable shelf-life. The studies showed that the lowest POD and PPO activities were found at 60°C, with pressure at 600 and 100 MPa, respectively. Castellari *et al*¹², demonstrated that for complete inactivation of grape PPO it is necessary to use high-pressure processing treatments in conjunction with a mild thermal treatment (40–50°C). For thermally processed carrots, adopting HPP as a pre-processing tool in combination with mild temperatures diminishes thermo-softening remarkably⁵¹.

The Effect of Hpp On Pathogens

High pressure processing main intention is to reduce microbial load and inactivate enzymes in the food. If not processed properly they may result in product deterioration and endanger the health of consumers. According to Huang *et al*²⁹, a pressure of 50 MPa can affect or inhibit protein synthesis and results in the reduction of number of microbial ribosomes. A pressure of 100 MPa required cause partial denaturalization of cellular proteins; when the pressure is increased to 200 MPa it produces internal damage in the microbial structure and external damage in the cellular membrane. Pressures equal or similar to 300 MPa produce irreversible damage to the microorganism, including leakage of intracellular components to the surrounding medium, resulting finally in cellular death. Yeasts, moulds and vegetative cells are sensitive to pressure and can be inactivated by treatment pressure between 300 and 600MPa. On the other hand, bacterial spores are highly resistant to pressure treatment, and thus would require high pressure above 1,200 MPa for their inactivation. Researchers shown that HPP treatment can inactivate yeasts like

Saccharomyces cerevisiae and *Listeria innocua* on diced apples, whole processed blueberries, strawberries and grapes. Vegetative cell count of *Talaromyces avellaneus* were reduced six-fold in apple juice using pressure of 200 MPa for 60 min or 300 MPa for 5 min. A high pressure of 600 MPa at 20°C was also effective in orange juice for reducing microbial load to a non-detectable level during a 4-week storage period.

CONCLUSION

HPP has evolved as a most promising technology due to its effective role in reduction of microbial load and inactivation of enzymes at low or moderate temperatures without changing organoleptic and nutritional properties and has the potential to be used in the development of a new generation of value added foods. HPP technology is commercially applied to many fruits and vegetable products (fruit juice, jams, purees, sauces). However they are not widely available in market. HPP of fruit and vegetable products has been revealed to preserve their phenolics and anthocyanins compounds and extend their shelf life and quality as well as to preserve their nutritional and functional characteristics. The process is very effective for retaining colour and flavor compounds of fruit and vegetable products during processing and storage, which is contrary to conventional thermal processing. The sensory properties of many HP-treated fruit and vegetable products are superior to those of products preserved in the traditional way by heat treatment. Some enzymes pose a major problem in fruit and vegetable products, however these enzymes can be inactivated at higher pressure but affect the rheological properties of the products therefore; the combined effect of HPP and thermal treatment is found to be very effective against inactivation of enzymes and create textures, which cannot be formed by thermal processing. This technique has an enormous benefit to both the food processing industry and consumers. The main limitation in using this technique with high pressure treatment is to safely and repeatedly generate high pressure

in a vessel, solid foods have to be processed in batch or semi continuous equipment. In addition, the capital cost of equipment is relatively high. Nevertheless, the use of pressure treatments and the range of products on which the treatments are applied continue to grow every year.

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