Malaysian Journal of Chemical Engineering & Technology 4 (1) (2021) 32–38

Malaysian Journal of Chemical Engineering & Technology

Journal Homepage: http://myjms.mohe.gov.my/index.php/mjcet

High pressure process treatment (HPP) as an alternative food preservation method on fruits and vegetables: A brief review

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Abstract

Highly processed and ready to eat food keep has been in high demand from the consumers from day to day. Thermal pasteurisation can lead to undesirable sensory changes and there could be a high risk in ingesting pathogenic microbes from lack of proper pasteurisation. High-pressure processing (HPP) could be a new alternative to preserve foods such as fruits, vegetables and fermented foods since it is less aggressive. The influence of HPP for the preservation of fruits, vegetables and fermented foods was proven to be effective towards the physicochemical properties of fruits and vegetables. The paper review in brief the effect of high-pressure process treatment as an alternative food preservation method. Observations were based on the physical and chemical properties such as colour, texture and microbiological counts. This study demonstrated that the quality changes of foods can be preserve through HPP treatments.

Article Info

https://doi.org/10.24191/mjcet.v4i1. 11233

Article history:

Received date: 16 November 2020
Accepted date: 24 April 2021
Published date:30 April 2021

Keywords:

High-pressure processing
Fruits
Vegetables

1.0 Introduction

Over the past years, there have been a significant increase in the demand for fermented food and plant-based processing food products. Plant-based food can be defined as both fruit and vegetable products. Fermented food is essentially a food substrate that is produced by edible microorganisms that is further hydrolysed through enzymatic action to convert to non-toxic food products that are pleasant and of attractive textures, aromas and flavours to the consumers. Fermentation plays several important roles in food processing such as providing detoxification to the food during the process and decreasing cooking time (Steinkraus, 2002). On the other hand, plant-based food is subjected to food processing to increase the palatability, edibility and extend shelf-life while maintaining its original nutritional properties (Oey et al., 2008).

Traditionally, food thermal processing will be used to ensure microbiological safety and prolong the shelf life of food products (Yuan et al., 2018). Thermal processing is subjected to high temperatures mainly to destroy deteriorative enzymes, spoilage and pathogenic microorganisms. A large amount of energy is transferred to the food, resulting in unwanted reactions which then lead to undesirable sensory changes and nutrient degradation effects (Oliveira et al., 2015). In fruit-based products, thermal processing has been used in extending shelf-life and microbiological safety (Yuan et al., 2018). However, this type of pasteurisation is not feasible to retain the original fresh flavours and there could be a high risk in ingesting pathogenic microbes because of lack of proper pasteurisation (Huang et al., 2020). It is also proven in Bao et al. (2016), where pickled radish that undergo thermal processing could result in texture softening, loss of vitamins and flavours.

Therefore, there is a growing interest in developing a non- thermal processing technology for the extension of the products shelf-life without effecting the quality of processed foods other than the conventional thermal method. In recent years, High Pressure food processing (HPP) treatment has become one of the promising non-thermal preservation methods for raw fruit and vegetables products and processed foods (Marszałek et al., 2015; Oliveira et al., 2015). This treatment started to be commercialized mainly for fruit preparations, salad dressings and sauces in the Japanese, American and European market (Tsevdou et al., 2019). HPP is a non-thermal technique of food preservation that may inactive vegetative bacteria and spores at refrigeration or mild process temperature using intense pressure. This technique not only can ensure the safety of food in terms of microbiological safety and gives limited impacts on nutritional values, but it is also gain more positive consumer appeal as it can extend the shelf-life of products longer compared to the conventional ways of preservation. Evelyn & Silva (2019) mentioned that different parameters used by the HPP treatments such as pressure level, holding time and storage conditions after the treatments can give a huge impact on the processed food shelf life by extending the life span to 3–10 times that of untreated foods.

According to Sohn & Lee (1998), HPP treatment at 400–600 MPa may maintain the palatability of kimchi during the 2 weeks storage periods. The number of microorganisms is decreased whenever there is an increment in the pressure applied. This treatment also doubled up the shelf life of the pre- packed kimchi and may be suitable to produce commercially produced kimchi products. Kimchi is a type of traditional fermented vegetable dish in Korea as one of the essentials in Koreans' dietary life. Chinese cabbage or Chinese radish are the usual vegetables to be used together with additional materials in the making of kimchi. Cabbage or radish will be soaked in salt solution (15% w/v) for approximately 2 hours. It will then be washed with tap water and left to drain for more than 1 hour. Other additional ingredients such as powdered red pepper, sugar and ginger were added to the cabbage and mixed well. The kimchi was stored at 20 °C for 3 days for fermentation (Sohn & Lee, 1998). The optimal pH value for kimchi is 4.2–4.5 with acidity ranges between 0.4–0.8% (Di Cagno & Coda, 2014).

Tempoyak is another type of fermented food made from a durian pulp when overripe, cracked or in poor quality with or without the addition of salt which then will let to ferment under partial anaerobic condition in a tightly closed container at ambient temperature or in a freezer. The pulp which usually in creamy yellow comes with a distinctive pungent smell. In Asian countries especially in Malaysia and Indonesia, *tempoyak* is consumed as a side dish or can be mixed in both fish and vegetables dishes. Fermentation usually takes around 7 days minimum for the development of flavour and acidity and can be fermented more for months. The sour taste in *tempoyak* is produced by lactic acid bacteria (LAB) with approximate of 2.8 to 3.6% acidity. During the fermentation period, texture of the durian pulp also changes from a solid to a semisolid state. The pH value of *tempoyak* ranges from 3.96 to 4.08 (Chuah et al., 2016). It is safe to say that *tempoyak* is produced during fruiting season as durian is a seasonal tropical fruit and domestically produced mostly only for self-consumption. Tan et al. (2019) stated that HPP treatment can effectively prolong shelf life of durian paste or *tempoyak* for a minimum of 56 days.

Some of the treatment on HPP of fruits are shown in Table 1. Aronia berry puree has been subjected to 400 and 600 MPa for 5 minutes during HPP treatment. It was observed that the treatment successfully inactivated yeasts and moulds with no regrowth. Yeasts and moulds are the examples of microorganisms that are sensitive to HPP. It will inactivate within few minutes by 300–400 MPa at room temperature (Muntean et al., 2016). The effectiveness of HPP treatment is proven in extending the microbial shelf life of Aronia berry puree for 8 weeks of refrigeration (Yuan et al., 2018). Other than that, fermentation and browning in preservation of fresh cut peaches were completely inhibited and peaches were able to preserved for at least 21 days at 10 °C (Denoya et al., 2015). HPP also successfully employed to preserve and extend the shelf life of mango cubes for 9 weeks by using 300 and 600 MPa for 1 minute at 3 °C (Abera, 2019). No apparent cloud loss in orange juice was observed for more than 50 days at 700 MPa at 1 minute of treatment (Nienaber & Shellhammer, 2001).

HPP was used to improve sensory properties and preserved texture on covalent bonds of foods (Mandal et al., 2018). Colour, flavour and texture are the most important factors in determining the acceptance of consumers for a certain food based on sensory

Table 1: Effect of HPP treatment on shelf-life of other food products

Conditions	Products & Results	References
300 & 600 MPa/ 1 minutes at 3 °C	Mango cubes: 9 weeks	(Abera, 2019)
700 MPa/ 1 minute	Orange juice: no cloud loss for >50 days	(Nienaber & Shellhammer, 2001)
500 & 600 MPa / 5 minutes	Durian paste & pulp: 56 days	(Tan et al., 2019)
400 – 600 MPa/ 5 minutes	Aronia berry puree: 8 weeks	(Yuan et al., 2018)
500 MPa/ 5 minutes	Fresh cut peaches: 15 – 21 days	(Denoya et al., 2015)
550 MPa/ 5 minutes	Pickled radish: 60 days	(Bao et al., 2016)

perception. Some of the physicochemical properties measured are shown in Table 2. HPP may conserve the food well without much effect towards the food's covalent bonds and hence this technique is suitable to use on fruits and vegetables (Oey, Van der Plancken, et al., 2008). HPP treatment can increase not only their shelf life but also their edibility and palatability of fruits and vegetables by using different pressure and temperatures. During the storage and distribution process, the quality of the HPP processed products however, can change due to the chemical reactions such as oxidation and biochemical reactions (Oey, Lille, et al., 2008).

High pressure treatment has higher potential of changes in food quality in terms of appearance and texture of food compared to the unprocessed products (Oliveira et al.,2015). At low and moderate temperature, HPP treatment has a limited effect on pigments that responsible for the colour of fruits and vegetables such as carotenoids and chlorophylls. Texture of fruits and vegetables can change in nature because of the transformations in cell wall polymers due to the enzymatic and non-enzymatic reactions. Based on research, human tongue can differentiate three main qualities of taste that are sweet, sour and bitter. Any changes in the three qualities may result in changes in their flavour. It is assumed that fresh flavour of fruits and vegetables will not change due to the high-pressure process. The small structure of molecular flavour compounds is not directly affected by high pressure (Oey, Lille et al., 2008).

There are several studies that discussed on the effect of HPP treatment on the sensory properties and texture of foods. Zhang et al. (2011) has stated that during the high pressure treatment at 600 MPa the colour of treated watermelon juice was similar to the control which is red in colour while high pressure treatment at 300 and 900 MPa respectively will cause a slightly different colour from the control. It was shown that, 600 MPa was sufficient in keeping the colour of the treated watermelon juice thus avoiding browning effects. Similar trends were observed on citrus juices like oranges, grapefruits and tangerines. Only a slight visible difference was observed between the treated and control juice at 600 MPa for 10 minutes at temperature between 4–15 °C (Hartyáni et al., 2011). Apart from the changes in colour, the texture differences also play an important key point in observing the effect of HPP treatment on foods.

According to Ahmed et al., (2005), the viscosity of the mango pulp was increased which led to the changes in texture, based on the shear-stress-rate. The mango pulp has been treated with 100/200 MPa for 15–30 minutes at 20 °C. Pre-cut mangoes when treated at 600 MPa will undergo browning effects and considerably developed slight- off flavours during storage (Boynton et al., 2002). As for the fermented food, durian paste or *tempoyak* have shown no significant changes in any part of the physicochemical properties. Even after HPP treatment at 500 and 600 MPa for 5 minutes, the durian paste showed no changes compared to the untreated (Tan et al., 2019).

Untreated food has to be packed prior to HPP treatment; packaging materials is one of the important components that need careful consideration. To achieve optimum pressure transmission, the food itself need to have no gas inclusions, no empty spaces in the packages with high moisture content. The packaging

Table 2: Effect of HPP treatment on physicochemical of food

Conditions	Products & Results	References
600 MPa/ 10 minutes	Orange, grapefruit & tangerine juices: significant alterations in colour &sensory evaluation	(Hartyáni et al., 2011)
600 MPa/ 5, 20, 40, 60 & 60 minutes at 60 °C	Watermelon juice: browning & alterations on dynamic viscosity	(Zhang et al., 2011)
600 MPa/ 1 minute at 3 °C	Pre-cut mango: colour, texture & other sensory attributes changed	(Boynton et al., 2002)
100/200 MPa, 15–30 minutes at 20 °C	Mango pulp: viscosity increased (change in texture)	(Ahmed et al., 2005)
500 & 600 MPa/ 5 minutes	Durian paste & pulp: no significance changes	(Tan et al., 2019)

materials need to be flexible enough to withstand the rapid compression and decompression upon pressure release. Numerous researches were done to study the effect of high- pressure processing on monolayer and multilayer laminate films used in the manufacture of packaging films. Common conditions that occurred during the exposure of packaging materials towards high pressure were reversible and irreversible changes. Reversible changes usually observed in packaging materials during the treatment in compare to irreversible changes that results in visible deformations (Marangoni Júnior et al.,2019). Deformations can be explained when the absorbed gases within layers of films and polymers were under pressure and the presence of gases in the polymer acts as a plasticizer which will change the polymer crystallinity. The pressure exerted is then released during decompression. Rapid decompression may cause blisters because of the rapid increase on the specific volume of food sample.

The most common packaging materials of laminated flexible packaging is from different combinations of polymers. Polypropylene (PP), polyethylene (PE) pouches and nylon cast polypropylene pouches are the best suited plastic packaging materials for HPP as these materials has their reversible response to compression, flexibility and resiliency (Marangoni Júnior et al., 2019; Muntean et al., 2016). Rigid materials such as metal and glass are not recommended as they will irreversibly collapse, break and eventually damage the lock system.

Carton package is also one of the materials that is not suitable for HPP since the pressed fibres can lose its own rigidity. Nowadays, the best suited packaging are the flexible packs, trays, bottles and jars. To maintain the flexibility of materials, heat seal is the most important parameter to be measured. A double 5–10 mm sealing per area is suitable for a good strength resistance to ensure vapor-tightness and reducing the risks of defects. Apart from flexibility, dimensional stability also plays an important role in preventing deformations. Defects such as wrinkles or holes can lead to aesthetic changes which will make the products to get rejected. Reduction of head space is another important factor to avoid unnecessary tension which will lead to a non-uniform processing. This situation occurred when the trapped air inside the packaging gives greater compressibility than the food. Vacuum packed technology can be used to reduce head space in a package (Marangoni Júnior et al., 2019). Yet, the most flexible and ideal packages for HPP treatment is vacuum packed products as it could be compressed for about 15% with no structural damage and will be able to return to its original shape (Muntean et al., 2016).

The packaging materials need to be pre-heated first with high temperature before undergo high-pressure process to avoid any undesirable changes in the properties of packaging materials and food quality. This step needs to be performed in the shortest time possible during the total time of food processing (Marangoni Júnior et al., 2019). Similarly, to the other developing technologies HPP treatment also have several limiting aspects that need to be taken into consideration. Other than having limited options for the packaging materials, the cost of equipment for this type of process is considered to be an expensive option compared to others. Food products in HPP can only be in a batch system or a semi-continuous process. The foods that need to be processed in a HPP processor should have 40% free water for anti-microbial effect upon treatment (Muntean et al., 2016).

HPP method was introduced into the food industry to ensure the microbiological safety and extend shelf life of food products. However, there is still insufficient study on the influence of HPP on the quality of food especially for fermented fruits and vegetables based on their physicochemical properties such as colour, texture and moisture content. The effects of different pressure used in HPP processing on the quality of foods during storage is also discussed in this study. This study would provide comprehensive technical support for the application of HPP in fermented fruits and vegetables.

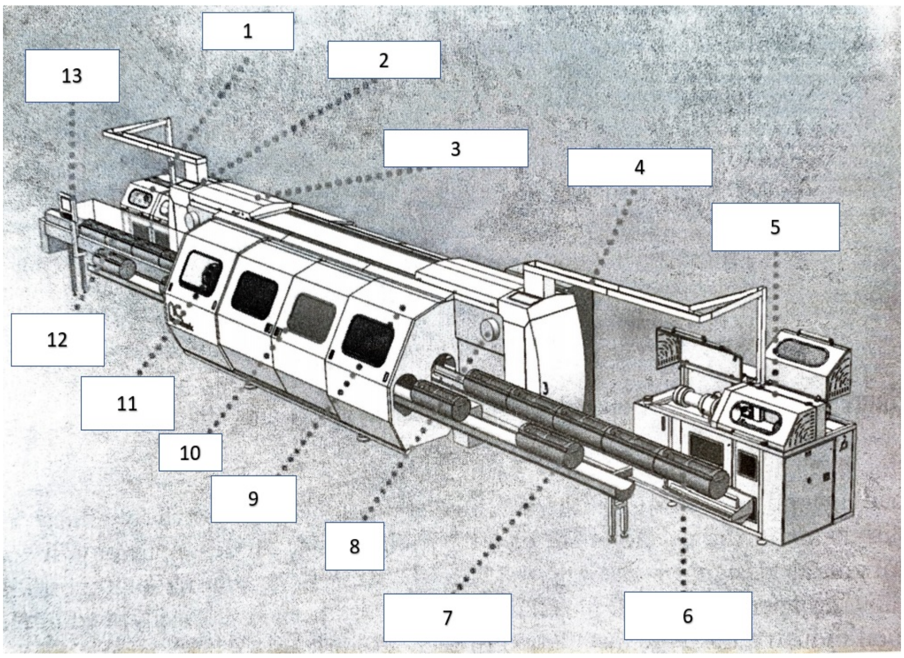
2.0 High-pressure processing

High pressure food processing or HPP treatment is a non-isothermal food pasteurisation that focus on an intense pressure for the inactivation of pathogenic microorganisms and spoilage of enzymatic complexes (Oliveira et al., 2015). Typically, pressures at 400–600 MPa are being used to operate industrially. This pressure range usually can treat any liquid and solid food with high moisture content to achieve pasteurisation at refrigeration or mild process temperatures (<45 °C) for processing times between 5–10 minutes (Evelyn & Silva, 2019; Muntean et al., 2016). Evelyn & Silva (2019) also mentioned that different parameters used by the HPP treatments such as pressure level, holding time and storage conditions after the treatments can give a huge impact on the processed food shelf life by extending the life span to 3–10 times greater than that of untreated food. Packaging characteristics also plays a big role in maintaining the quality of HPP foods. As stated by Denoya et al. (2015), HPP treatments can be a substitution for the conventional thermal treatments as it can be applied at room temperature with or without high temperature effects towards preserving the food. HPP treatment maintain the freshness and nutritional value of the food products compared to thermal treatment where a large amount of energy is transferred to the food. Hence, any unwanted reactions may be triggered which lead to undesirable changes in sensory and nutrient degradation (Oliveira et al., 2015).

A high-pressure process system needs a pressure vessel that follow the isostatic rule regardless of the food size and shape. According to Koutchma (2014), based on the isostatic rule, an instantaneously pressure will be uniformly transmitted in the vessel throughout the sample either it is directly contact with the pressure medium or sealed in a flexible package. The time needed for the high-pressure process however should be independent from the size of sample. Isostatic rule or isostatic compression occurred when there is pressure-transmitting fluid which will cause volume reduction up to 19% as a result from the compressibility process depending on the final temperature and pressure reached. Transmitting fluid serves several functions primarily for the transmission of power or pressure. For example, the compressibility values will increase for about 15% at 600 MPa with the used of water as the transmitting fluid.

In contrast, the presence of dissolved air or gases can give unfavourable impacts to the performance of the fluid by causing a delay in the response rate. Another key function of the transmitting fluid is for lubrication. The fluid will minimize wear and reduces friction all at once by forming a layer of film to separate metal to metal contact between surfaces. Contaminants between gaps and crevices can also be removed by the fluid as they will only torn off the surfaces and rapidly wear off (Rathnakumar & Martínez-Monteagudo, 2019). Le Chatelier's principle describes that any phenomenon such as phase transitions, chemical reactions and changes in molecular configuration were stimulated by high pressure and accompanied by a decrease in volume. The effect of HPP on food chemistry and microbiology and effects of pressure on protein stabilisation are both governed by this principle (Koutchma, 2014).

As illustrated in Fig. 1, the fluid reservoir above is used as a storage tank to hold the transmitting fluid and it may vary in size and shape either in rectangular, cylindrical or T-shape. The material of construction can also vary in steel, stainless steel or aluminium. It is designed to store between two to four times of the pump flow to maintain a continuous supply of fluid in the intensifier. The intensifier that comes with a large cylindrical rod needs a constant supply of fluid as the volume of the returning fluid will be reduced with every blow of the piston. High-pressure vessel functions as a point of contact between the packed food



Number	**Components**
(1)	Intensifiers 1 & 2
(2)	Relief valves
(3)	Main water tank
(4)	Electrical cabinet
(5)	Intensifiers 3 & 4
(6)	Product inlet line
(7)	Baskets return conveyor
(8)	Yoke
(9)	Enclosure
(10)	Vessel
(11)	Plugs and wedges
(12)	Product outline line
(13)	Panel

Fig 1.:Simplified diagram of HPP components in a HPP system (Proctor, 2011)

and transmitting fluid. There are three different types of high-pressure vessels used for HPP such as thick-walled or monobloc, multiwalled and wire- wound. Each of this type of HPP need specific requirements for the pressure vessels design features, shape of the vessel and thickness of the wall.

3.0 Conclusions

Generally, fruits and vegetables can be treated with high-pressure process treatment as well as preserving the original fresh flavours and nutritional values in the food. This treatment could be a promising emerging technology in the food industry as it can extend the shelf life of foods up to 3 to 10 times longer compared to untreated food. HPP treatments can be operated at pressure ranges from 100–700 MPa (industrially), with processing time up to 30 minutes per cycle depends on samples used. The pressure range used in this study can treat any liquid and solid foods at refrigeration or mild process temperatures at below 45 °C. The effects of HPP on the physical and chemical properties of foods are both governed by isostatic and Le Chatelier's principle. HPP treated food can be observed on texture profile analysis, pH meter and microbiological analyses. Findings of this study could help processors to commercialize HPP usage in developing fresh-like fruits and vegetables products.

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