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Effects of High-Pressure Processing on Milk, Meat, Fruit, and Vegetable: A Review

I Putu Karang Adisurya* and Anjar Ruspita Sari

Agroindustrial Product Development, Department of Bioresources Technology and Veterinary, Vocational College, Universitas Gadjah Mada, Yogyakarta, Indonesia
Corresponding author. Email: karangadisurya@mail.ugm.ac.id

ABSTRACT
Preservation of agricultural products is needed to extend shelf life and maintain quality. One of the preservation methods that can be used is High-Pressure Processing (HPP). This article aims to review the effect of implementing HPP on milk, meat, fruit, and vegetable. The results of the review showed that the main effect of HPP with 400-600 MPa was generally effective in reducing/inactivating pathogenic bacteria in dairy and meat products. In fruit and vegetable, HPP is effective in retaining phenolic compounds, antioxidants, and volatile compounds to maintain the nutritional content of the product. The critical point in the application of HPP is the pressure and temperature range that be used, processing time, and target to be achieved. However, HPP causes slight changes in components, such as protein denaturation in milk and fat oxidation in meat, so adjustments are needed to critical points. It can be concluded that the preservation of products with HPP can improve the sensory quality and extend the product shelf life with a lower risk of damage to the component and sensory characteristics compared to thermal processing.

Keywords: *fruit, HPP, meat, milk, and vegetable.*

1. INTRODUCTION

Agricultural products such as milk, meat, fruit, and vegetable have perishable characteristics, so proper processing is required. Methods that can be used to maintain quality and extend the shelf life of agricultural products are pasteurization and sterilization. In dairy products, pasteurization is carried out by heating at a temperature of 75-85oC for 15-30 seconds. Pasteurized milk can last for several days at a storage temperature of 4oC. Sterilization is the process of heating milk to a temperature of 138-145oC for 2-5 seconds that can last up to several months at room temperature. Both of these processes can provide physicochemical changes to milk depending on the temperature and time used. In particular, pasteurization and sterilization can affect the solubility, nutritional value, and organoleptic quality of milk [1].

The Processing of meat and vegetable into "pate" products also requires a sterilization process using a temperature of 100oC. These conditions cause a decrease in pH, protein denaturation, and carbohydrate degradation. Long thermal processes with high temperatures such as sterilization will cause the meat to decrease in color, taste, and texture [2]. In fruit, processing of fruit juice using a temperature of 40-50oC is known to cause modifications to quality attributes, especially the aroma. This has led to a trend in the industry to minimize the thermal processes and to develop research on fruit juices using non-thermal processes [3]. It can be said that processing meat, fruit, and vegetable products using thermal processes also poses a risk of quality degradation, as in dairy products.

That risk can be overcome by non-thermal processing, one of which is by the high-pressure processing (HPP) technique. HPP as a non-thermal technique for food preservation by inactivating pathogenic bacteria and harmful vegetative microorganisms by applying pressure to induce the pasteurization effect [4]. The pressure range used in this method is 100-900 MPa at room temperature [5], [6]. As a non-thermal preservation process, HPP can maintain the quality of the sensory and nutritional attributes of the food product to be preserved [7]. In this article, we will review the effect of the HPP technique for the preservation of milk, meat, fruit, and vegetable.

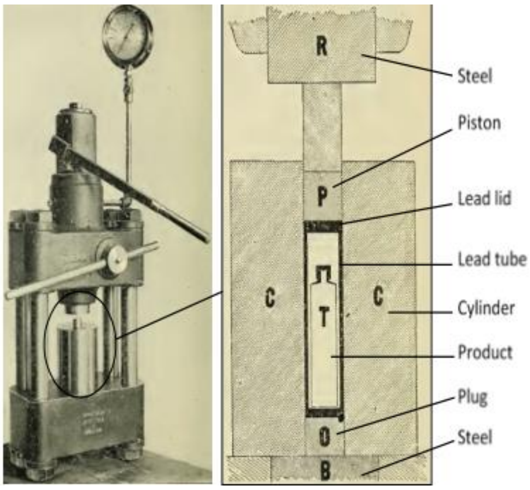

Figure 1 First HPP Equipment [8,9]

2. HIGH-PRESSURE PROCESSING (HPP)

High-pressure processing (HPP) was first used by Hite in 1899 to process milk. Hite puts the milk in a tightly closed tin tube container, then the container is put in a tin tube. The tin tube is filled with water and tightly closed with a tin cover, then placed on a steel cylinder. The steel cylinder is locked with a steel plug at the bottom, then placed between two steel blocks. Pressure is subsequently applied to the object using a steel piston [8], [9]. An illustration of the earlier HPP equipment used by Hite can be seen in Figure 1.

The principle of HPP is to affect pressure-sensitive non-covalent bonds, so this method can maintain quality, natural freshness, and extend the product shelf life [10]. Low molecular weight components, such as nutritional components and sensory characteristics will not be affected. On the other hand, high molecular weight components such as tertiary structures that determine the functional properties of the product will be affected [11]. The shape of the product can also be maintained using this method because the application of pressure is applied uniformly and simultaneously in all directions (isostatic pressure), so the product will not crumble during treatment4. HPP is also capable of reducing and inactivating pathogenic and spoilage microorganisms. The mechanisms are changing cell structure and physiological function, breaking DNA chains, disrupting cell membrane integrity, deactivating enzymes and membrane selectivity, and denaturing microorganism proteins thereby will improve quality and extend the product shelf life [12].

HPP is currently being applied to food processing and some commercial fruit and vegetable products [13]. Some of the advantages of using HPP are killing vegetative bacteria, maintaining product quality, speeding up product processing time, allowing products to be processed directly with their packaging. In addition, HPP advantages are potential to reduce or eliminate chemical preservatives and excess thermal treatment, and also increase consumer appeal. Some of the disadvantages of HPP are that it slightly affects product components, expensive equipment costs, some microbes that still can survive, limited packaging options, and regulatory challenges [14].

3. EFFECTS OF HPP ON MILK

Cow's milk that is processed using HPP has almost the same quality as milk that is processed using the high-pressure short time (HTST) or sterilization technique. HPP with a pressure of 600 MPa for 5 minutes can be regarded as alternative pasteurization to process raw milk. HPP combined with microfiltration effectively reduces bacteria up to 4 log units [15]. Applying pressure of 400-600 MPa gradually for 1-3 minutes effectively inactivates E. coli, Salmonella spp., and L. monocytogenes. The reduction number of the three bacteria has occurred significantly at a pressure of 400 MPa for the first 1 minute with a reduction value of 0.85, 1.09, and 1.42 log units, respectively, compared to the raw milk [16].

The inactivation process of B. cereus showed an increase in temperature was directly proportional to the increase of inactivated spores. An increase in temperature of 38-70oC with a pressure of 600 MPa for 40 minutes was able to inactivate B. cereus spores up to 3.5 log units [17]. HPP with a pressure of 900 MPa with temperatures of 80oC, 90oC, and 100oC resulted in a shorter D value (decimal reduction time) for inactivating C. sporogenes bacteria than at 700 MPa at the same temperature. The D values of C. sporogenes at a pressure of 900 MPa for temperatures of 80oC, 90oC, and 100oC were 9.11, 3.83, and 0.73 minutes, respectively, significantly shorter than those at a pressure of 700 MPa with a D value at 80oC, 90oC, and 100oC were 17.0, 8.4, and 1.0 minutes, respectively [18]. Thus, the higher temperature used for HPP, the greater number of bacteria will be reduced [19].

HPP using waterjet is also known to affect the structure and physicochemical characteristics of milk. The research showed that milk processed with HPP at a pressure of 500 MPa, 1-30oC showed variations in the size and structure of casein micelles. This structural change caused by porosity and density in casein micelles changed as a result of processing milk using HPP with waterjet. However, these changes did not affect the stability of milk that was stored for 14 days, 4oC [20]. For milk-gelatin mixtures, medium to high pressure (300-600 MPa) at room temperature for 15 minutes shows change in microstructure of the mixture depending on the solids content. The application of HPP of the milk-gelatin mixture can increase the viscosity of the mixture due to the segregation phase between the two polymer components [21].

Regarding the chemical characteristics, the application of HPP with a pressure of 600 did not affect the fat compounds in milk [22]. Even with a higher pressure of 900 MPa it also did not affect the fat and fatty acid compounds in cow's milk [23]. However, protein compounds appear to be affected by HPP. The application of HPP can denature whey protein α-lactalbumin (α-la) by 6% and β-lactoglobulin (β-lg) by 41-59% [15]. This is because β-lg has a higher sensitivity to pressure so it is easier to denature when milk is processed using HPP, so the main factor that affecting β-lg denaturation is the duration of HPP used [22].

4. EFFECTS OF HPP ON MEAT

Processing of meat using HPP with a pressure range of 400-600 MPa for 3-7 minutes at room temperature is generally effective for inactivating pathogenic and spoilage microorganisms by 4 log units. This leads to an increase in the shelf life and safety of the meat. Research shows that HPP also induces changes in meat color attributes, which is more significant in red meat than white meat and other processed meat products. However, this condition depends on the myoglobin content in the meat. This can be overcome by adjusting the pressure, duration, and temperature used for HPP [24]. HPP has also been shown to be able to inactivate several bacteria and increase freshness in chicken breast filet. Applying HPP with a pressure of 450 MPa at 15 ± 3oC for 5 min was effective to inactivate E. coli and L. monocytogenes bacteria, and reducing S. typhimurium by > 3 log units. Giving a higher pressure of 600 MPa at 15 ± 3oC for 5 min is effective to inactivate all these bacteria and increase the shelf life of 7-14 days. The negative impact that arises is that pressure affects the characteristics of taste, aroma, and freshness in the chicken breast filet [25].

The implementation of HPP also has an impact on beef. HPP under the pressure of 200 MPa for 20 minutes has a more minimal effect than at a pressure of 400 MPa at 20-40oC. A pressure of 200 MPa proved to be more effective for improving beef hygiene. At higher pressures, HPP will increase lipid oxidation in beef, but pressure range of 200-400 MPa will not change the fatty acid profile of beef. Processing beef with a pressure of 200 MPa also did not change the pH, but pressure of 300-400 MPa was able to induce an increase of pH value and affect the color of beef [26]. On the other hand, HPP applied to pork showed effectiveness in inhibiting post-mortem activity so that it could inhibit water loss in meat [27]. Pressures up to 200-400 MPa at room temperature for 20 minutes have been able to inhibit the rigorous process in pork thereby increasing the texture of the meat to be more tender [28], [29]. The application of higher pressure causes the prevention of the rigorous process to take place continuously due to physical and functional changes in pork [30]. In addition, HPP also increases brightness and tenderness, however also slightly increases pork lipid oxidation [27].

The extraction process of blue crab meat using HPP shows that applying pressure of 100-300 MPa with a temperature of 10oC for 5 minutes is proven to increase the extraction yield compared than using the thermal process. In addition, the extraction process can also be done more quickly. The use of higher pressure of 600 MPa with a temperature of 10oC for 5 minutes resulted in a higher amount of meat extraction than at a pressure of 100-300 MPa. Sensory analysis of blue crab meat processed at HPP pressures of 300 and 600 MPa showed higher elasticity and juiciness values as well as better visual appearance [31]. The research results showed that HPP affected the protein components of blue crab meat. The application of pressure < 500 MPa is known to induce denaturation of myosin protein although not completely [32]. This can be caused by a decrease in the α-helix structure and β-turns due to high pressure [31].

In processed meat products such as sausages, the application of HPP with a pressure of 540 MPa at 10oC for 2,5 minutes was effective for reducing Enterobacteria, E. coli, Pseudomonas, Enterococcus spp. up to < 10 cfu/g thereby increasing product hygiene and safety [33]. The application of HPP with a pressure of 400-600 MPa with a temperature of 18oC for 0-12 minutes has been shown to reduce the amount of L. monocytogenes to < 100 cfu/g [34]. However, if HPP is applied to sausage products with a pressure of < 400 MPa, research shows it is not effective in reducing the number of pathogenic bacteria significantly [35]. In addition, HPP > 400 MPa for sausage products also has a negative effect in the form of myoglobin denaturation and unsaturated fat oxidation [36]. However, compared to the thermal process, there are fewer changes associated with fat oxidation and protein denaturation when sausage is processed by HPP [35].

5. EFFECTS OF HPP ON FRUIT AND VEGETABLE

HPP is known to increase phenolic and anthocyanin compounds, maintain nutrition and extend the shelf life of fruit and vegetable products. In addition, HPP is also effective in maintaining the color and taste characteristics of fruit and vegetable products [37]. Fruit and vegetable contain phenolic compounds that function to nourish the body. Currently, many consumers consume fruits and vegetable in the form of juice so that the content of phenolic compounds in fruit and vegetable juices must be maintained. Preservation of fruit and vegetable juices using HPP is generally able to retain phenolic compounds and anthocyanin pigments

Table 1. Compilation of Studies on Effects of HPP on Milk, Meat, Fruit, and Vegetable

Product	HPP Treatment	Effects	References
Milk			
Whole milk	400-600 MPa, 1-3 min	Effective for inactivating *E. coli*, *Salmonella spp*., and *L. monocytogenes.*	[16]
	500 MPa, 1-30ºC	Showed variations in the size and structure of casein micelles	[20]
	600 and 900 MPa	Did not affect the fat and fatty compounds.	[22,23]
	600 MPa, 38-70ºC, 40 min	Effective for inactivating *B. cereus.*	[17]
	900 MPa, 80-100ºC	This resulted in a shorter D (decimal reduction time) value for inactivating *C. sporogenes*	[18]
	In general	Denature whey protein α -lactalbumin (α-la) by 6% and β-lactoglobulin (β-lg) by 41-59%.	[15]
Milk with gelatin	300-600 MPa, at room temperature 15 min	Increase the viscosity of the mixture due to the segregation phase between the two polymer components.	[21]
Meat			
Beef	200-400 MPa, 20 and 40ºC 20 min	Effective for improving beef hygiene and does not change the fatty acid profile and pH.	[26]
	400-600 MPa, at room temperature 3-7 min	Generally effective for inactivating pathogenic and spoilage microorganisms by 4 log unit, but increase lipid oxidation, induce an increase of pH value and affect the color of beef.	[24,26]
Chicken breast filet	400 MPa, 15 ± 3ºC, 5 min	Effective for inactivating *E. coli* and L. *monocytogenes*, and reducing *S. typhimurium* by> 3 log units.	[25]
	600 MPa, 15 ± 3ºC, 5 min	Effective for inactivating all these bacteria: *E. coli, L. monocytogenes, S. typhimurium,* and increase the shelf life of 7-14 days.	[25]
Pork	200-400 MPa, room temperature, 20 min	Effective for inhibiting the rigorous process in pork, increases brightness and tenderness, but slightly increases pork lipid oxidation.	[27,29]
Blue crab meat	100-300 MPa, 10oC, 5 min	Increase the extraction yield compared to using the thermal process, higher elasticity, and juiciness values.	[31]
	600 MPa, 10ºC, 5 min	Higher amount of meat extraction than at a pressure of 100-300 MPa and higher elasticity and juiciness values.	[31]
	< 500 MPa	Induce denaturation of myosin protein.	[32]
Sausage	540 MPa, 10ºC 2,5 min	Effective for reducing *Enterobacteria*, *E. coli, Pseudomonas, Enterococcus spp*. up to < 10 cfu/g.	[33]

	400-600 MPa, 18ºC, 0-12 min	Reduce the amount of *L. monocytogenes* to < 100 cfu/g.	[34]
	> 400 MPa	Myoglobin denaturation and unsaturated fat oxidation.	[36]
Fruit & Vegetable			
Whole fruit & vegetable	In general	Increase phenolic and anthocyanin compounds, maintaining the color, taste nutrition, and also extend the shelf life of fruit and vegetable products.	[37]
Fruit & vegetable smoothie	In general	Does not affect pH, total dissolved solids, product texture, and even increases the phenolic compounds and antioxidant content of fruit and vegetable smoothies.	[43]
	627,5 MPa, 20ºC, 6,4 min	Effective in reducing PME, POD, and PPO by 85%, 45%, and 10, respectively, and also maintaining or slightly increasing the color of the product	[43]
	630 MPa, 20ºC, 6 min, then stored at 25ºC	Reduce the number of mesophilic aerobic bacteria, *Enterobacteria*, mold, yeasts, and lactic acid bacteria to below the detection limit of < 1,0 log cfu/g for 26 days of storage and reduced the activity of PME, POD, and PPO by 83,9%, 31,4%, and 9,7%, respectively, at baseline after treatment.	[44]
Orange juice	600 MPa, 15 min	Effective for inactivating *Alicyclobacillus acidoterrestris* spores and allowed to reduce 3 log units after 42 minutes.	[40]
Pineapple juice	500 MPa, 10 min	Significant decrease in the number of aerobic bacteria from 5,60 cfu/ml to 0,59 cfu/ml after processing with HPP. The shelf life of the product can be maintained for 21 days at 4ºC. In addition, this treatment is effective for maintaining sugar content, pH, acidity, as well as color pigments, bioactive components, antioxidants, and volatile compounds.	[41]

compared to thermal processing [38]. Regarding color, HPP has little effect on chlorophyll, carotenoids, anthocyanins, and other pigments in fruit and vegetable [37]. The taste of fruit and vegetable is also not affected by HPP [39]. This caused by HPP affects non-covalent bonds, which are sensitive to pressure. Components with low molecular weight such as sensory characteristics (color and product) are not affected [11].

HPP is also able to reduce the number of aerobic bacteria in fruit juices. Orange juice treated with HPP at a pressure of 600 MPa for 15 minutes was effective to inactivate Alicyclobacillus acidoterrestris spores and allowed to reduce 3 log units after 42 minutes [40]. On the other hand, pineapple juice processed by HPP with a pressure of 500 MPa for 10 minutes showed a significant decrease in the number of aerobic bacteria from 5,60 cfu/ml to 0,59 cfu/ml after processing with HPP. The shelf life of the product can be maintained for 21 days at 4oC. HPP is also proven to be able to maintain the quality of pineapple juice during storage. Pineapple juice processed with HPP did not show significant changes in sugar content, pH, acidity, as well as color pigments, bioactive components, antioxidants, and volatile compounds were more maintainable than pineapple juice that was treated with thermal processes [41]. In addition, the use of HPP technology is also able to attract consumers' attention to pineapple juice. HPP technology, which is listed on the pineapple juice label increases the respondent's understanding, thereby increase buying interest [42].

In fruit and vegetable that are processed into smoothies, HPP is also known not to affect pH, total dissolved solids, product texture, and even increases the phenolic compounds and antioxidant content of smoothies. Enzymes that affect the quality of fruit and vegetable smoothies are peroxidase (POD), polyphenol oxidase (PPO) and pectin methylesterase (PME). These three enzymes cause loss of phenolic compounds and induce browning thereby reducing the nutritional and sensory quality of the product. The results showed that HPP treatment with a pressure of 627,5 MPa for 6,4 minutes at a temperature of 20oC was effective in reducing PME, POD, and PPO by 85%, 45%, and 10% respectively, and maintaining or slightly increasing the color of the product [43]. Thus, HPP is proven to maintain the nutritional content and sensory quality of smoothie products from fruit and vegetable.

Further research was conducted to determine the treatment of HPP under the pressure of 630 MPa for 6 minutes at 20oC in fruit and vegetable smoothies which were then stored at 25oC. The results showed that HPP treatment was able to reduce the number of mesophilic aerobic bacteria, Enterobacteria, moulds, yeasts, and lactic acid bacteria to below the detection limit of < 1,0 log cfu/g for 26 days of storage. In addition, it is also known that there is no change in the total dissolved solids and pH. Regarding enzymes, HPP reduced the activity of PME, POD, and PPO by 83,9%, 31,4%, and 9,7%, respectively, at baseline after treatment. This shows that increasing the applied HPP pressure can reduce the activity of PME, POD, and PPO. So, it can be said that HPP is effective in reducing the activity of pathogenic microorganisms and maintaining the nutrition and quality of fruit and vegetable smoothies stored at room temperature for up to 26 days [44].

4. CONCLUSION

The main effect of HPP on milk, meat, fruit, and vegetable is reducing and/or inactivating the pathogenic microorganisms to extend the shelf life of the product. However, HPP can cause denaturation of α-lactalbumin and β-lactoglobulin proteins in milk. HPP can inhibiting the rigorous process to keep the texture of the meat remains soft, but higher pressure can cause fat oxidation on meat. HPP also able to maintain the content of phenolic, antioxidants, and volatile compounds in fruit and vegetable. In general, HPP is proven to be able to maintain and improve product quality and shelf life with a lower risk of damage to the component and sensory characteristics compared to the thermal process. Accordingly, HPP can be used as the cutting-edge technology for non-thermal product preservation.

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