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Review Article

# Effect of High-Pressure Processing on Nutritional Composition, Microbial Safety, Shelf Life and Sensory Properties of Perishable Food Products: A Review

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## Abstract

*Many fresh and perishable food products offer optimal nutritional value. However, the products are easily spoiled within a short period due to high water and nutrient content. To overcome the problems, high-pressure processing (HPP) is one of the available emerging nonthermal technologies to inactivate the microbial load, maintain nutritional composition, sensory acceptability, and extend the shelf life of perishable food products. Therefore, the objective of this review was to assess the literature regarding the potential of HPP on the preservation of nutritional values, microbial safety, and sensory properties of perishable food products. The reviewed papers highlighted that the application of HPP from 400 to 600 MPa maintains sensory properties, low microbial count, and extended shelf life of products such as fruits and vegetables. Moreover, treatments of HPP from 100 to 400MPa are effective to preserving perishable animal products such as meat, fish, milk, cheese, and yoghurt through the destruction of pathogenic microorganisms, maintaining sensory properties, and increasing shelf life. The review showed that HPP effects on the shelf life, acceptability, safety, and nutritional values of perishable food products.*



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## INTRODUCTION

Fresh perishable food products have important nutritional value, but are not immediately consumed in some cases. Their perishability could be due to high water activity, low pH, and microbial growth. Such perishable products must be preserved to maintain the desired quality (James & Kuipers, 2003). Traditional food preservation technologies like pasteurization, sterilization, and drying ensure microbiological safety but might destroy heat-sensitive vitamins and polyphenols, affecting the food quality (Pereira & Vicente, 2010).

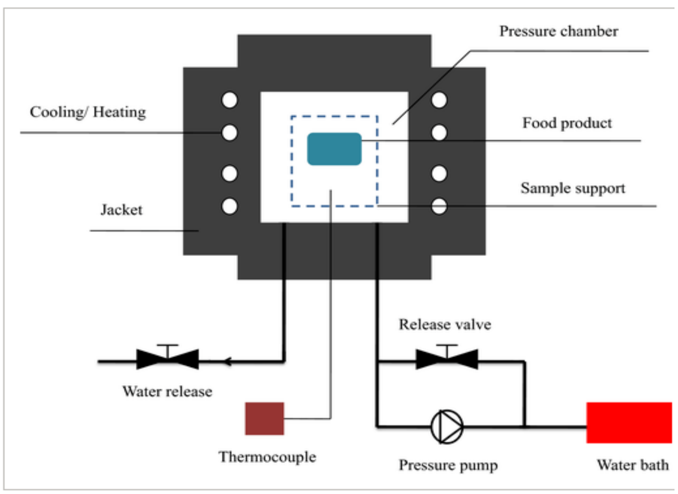
Traditional techniques for food preservation might require dehydration, heat addition, salt and sugar application, preservatives, and deep-freezing (Ramaswamy & Tessema, 2010). However, these methods can cause adverse effects on nutritional composition and sensory properties such as color, flavor, and texture (Queiroz *et al.,* 2010). Nowadays, discoveries of new technologies are key activities behind the increasing competitiveness among food industries to supply safe and better-quality products (Daher *et al,* 2017). Conventional methods and novel thermal processing had a significant impact on color, flavor, nutrient loss, energy inefficiency, and atmospheric pollution. Exploring new food preservation methods in which thermal processing severity is reduced and functional effects minimal is necessary. Non-thermal processes like HPP, pulsed electric field, irradiation, and ultra-filtration offer alternative treatments to thermal processes (Ramaswamy *et al*., 2008).

High-pressure processing (HPP) is a promising technology for reducing spoilage and maintaining food quality by preventing bacterial cell rupture and depressurization (Ramaswamy *et al*., 2008). This technology inactivates microorganisms, spores, and enzymes, preserving the sensory and nutritional quality of the products. Promoting and understanding the existing situation concerning the potential of HPP technologies for the preservation of nutritional values, microbial safety, and sensory properties of perishable food products with their commercial application and future outlooks is very important. This helps to improve future intervention research and expand the output of the research. However, there is limited study and comprehensive review in Ethiopia regarding the present scenario and future perspective of HPP on the quality of perishable products. Therefore, this review aimed to assess the literature regarding the potential of HPP on the preservation of nutritional values, microbial safety, and sensory properties of perishable food products. To achieve the objective of the review, different original research, review articles, and books have been reviewed in line with the potential of HPP on nutritional values, microbial safety, shelf life, and sensory properties of perishable food products such as fruits, vegetables, meat, fish, milk, cheeses, and yoghurt.

**Overview of HPP system**

High-pressure processing (HPP) is one of the non-thermal novel processing technologies that can produce foods of superior quality while preserving the qualities of fresh goods and lengthening their shelf life (Queiroz *et al*., 2010). It's a cold pasteurization technique where products are put into a vessel and exposed to high isostatic pressure (300–600 MPa) while still sealed in their final packaging. Food can be processed to preserve its nutrition, flavor, and fresh appearance while inhibiting harmful microbes and delaying deterioration by being compressed inside a high-pressure tank (Xu, 2005).

A high-pressure system comprises a high-pressure vessel, pressure-generation system, temperature control device, and material-handling system (Zhang *et al*., 2019). The pressure vessel is the most important component of high hydrostatic-pressure equipment. The pressure vessel is a crucial component of high hydrostatic-pressure equipment, transmitting pressure uniformly and instantaneously using fluids like water, glycol, silicone oil, sodium benzoate, ethanol, inert gases, and castor oil (Yaldagard *et al*., 2008). Food products should be packaged in flexible packaging and loaded into a high-pressure chamber filled with pressure-transmitting agent. This process compresses water surrounding the food, resulting in a small volume change. Once the desired pressure is reached, the pump or piston is stopped, valves closed, and the pressure is maintained without further energy input. Products are held at 600 MPa for 3-5 minutes, with 5-6 cycles per hour for compression, holding, de-compression, loading, and unloading. After treatment, the product is removed and stored conventionally (Yordanov & Angelova, 2010). Generally, the schematic representation of HPP consists of a Pressure Chamber, a Cooling/heating section, a Jacket, and a sample support as depicted in Figure 1.




**Source:** Zhang *et al.,* 2019

**Figure 1** The schematic diagram of a HPP system for treating food products

**Principle of HPP in food processing**

Pressure is an imperative thermodynamic parameter with unique effects on biological systems (Aertsen *et al*., 2009). High pressure in the food industry is transmitted isostatically within pressure vessels, based on Pascal's law and Le Chatellier's principle, regardless of food size, geometry, or constituents (Balasubramaniam *et al*., 2016). Both principles are directly relevant to the use of high pressure in food processing. Le Chatelier's Principle states that when a system is disturbed, it minimizes the disturbance by promoting volume-decreasing reactions. The Isostatic Rule states that pressure is uniformly transmitted throughout a sample under pressure, allowing pressure processing to be independent of sample size, unlike thermal processing (Hugas *et al*., 2002). High pressure impacts food depending on pressure and temperature's effects on thermodynamic and transport properties like density, viscosity, thermal conductivity, compressibility, heat capacity, diffusivity, phase transition properties, and solubility (Buckow *et al*., 2013). High-pressure treatment typically increases food temperature by 3°C per 100 MPa increase at ambient temperatures (~25°C) (Aymerich *et al.,* 2008). The heat of compression in food, triggered by compressive work against intermolecular forces, can increase by up to 9°C per 100 MPa increase (Rasanayagam e*t al.,* 2003).

**Effects of HPP on the food properties**

**The effects of HPP on microbial safety and shelf life of fruits and vegetables**

The major results reported on the effects of HPP on the microbial safety of fruits and vegetables are summarized in Table 1. Pressure treatments between 400 to 600 MPa are commonly applied to extend the shelf-life of apple puree products decreasing the counts of spoilage aerobic mesophilic bacteria, yeasts, and molds. After high-pressure treatments (at 400 to 600 MPa) for 15 to 60 minutes, apple puree resulted in a product with 3.3 and 3.2 logarithmic reduction of aerobic mesophilic bacteria and yeasts/molds, respectively; and the shelf life of the product extended to 14–21 days at 4 ºC (Landl, 2010). Similarly, Hartyáni (2013) found that a pressure treatment of 200 to 600 MPa for 5 minutes at 3 ºC decreased the level of Acidoterrestris and Alicyclobacillus, in apple and orange juice to 2.0 and 2.2, respectively. The result showed that the shelf life of apple and orange juice extended to 14 to 28 days at 4 °C. Treatment at 550 MPa for 2–10 min at 20 °C decreased total aerobic bacteria and Yeasts/Molds/ in banana to 2 and 2.5, respectively; and extended its shelf life to more than 15 days at 4 °C (Li, 2015). Syed (2014) also indicated that a pressure application of 700 MPa for 5 minutes at 4 ºC decreased total *Staphylococcus aureus* in orange juice to 6.2–6 and stayed without spoilage for up to 15 days at 4 °C.

The study on the effects of HPP on microbial safety and shelf life of fermented cabbage revealed that treatments of HPP at 300 MPa for 10 minutes at 40 °C reduced the total coliforms, aerobic mesophilic bacteria, lactic acid bacteria, fecal coliforms and yeasts/mold/ to <1, 4.2, 4.2, <1 and <1 logarithmic values, respectively (Penas *et al*., 2010). The result depicts that the shelf life of fermented cabbage extended for 60 days at 4 °C (Penas *et al*., 2010). The study conducted by Li *et al* (2010) also showed that the pressure treatments at 400–600 MPa for 10–30 minutes at room temperature on fresh sour Chinese cabbage reduced total aerobic bacteria to 2.7–4.5 from 6.2, lactic acid bacteria to 2.4–4.3 from 7.0 and yeasts to 1.5–2.0 from 4.2. This finding showed that the shelf life of the fresh cabbage was extended to 60 days at 4 °C. Furthermore, the study conducted on the application of HPP at 300–500 MPa for 10 minutes at 25 °C on tomato juices reduced Viable microbial Cells, Yeasts/Molds/, Enterobacteria, and Lactic acid Bacteria by 0.9–4.1, 3.7/3.6, 2.1 and 4.2, respectively. This result increased the shelf life of tomato juice to 28 days at 4 °C.

**Table 1:** Effects of HPP on microbial safety and shelf life of fruits and vegetables

| Fruit/vegetable type | Product type | HPP Conditions | Microbial Inactivation Criterion | Log Reductions | Shelf life | Sources |
|---|---|---|---|---|---|---|
| Apple | Puree | 400-600 MPa<br>15 min<br>20 °C | Aerobic, mesophilic, bacteria<br>Yeasts/Molds/ | 3.3<br>3.2 | 14–21 days<br>4 °C | Landl, 2010 |
| Apple<br>Orange | Juices | 200–600MPa<br>10 min<br>20–60 °C | Alicyclobacillus<br>Acidoterrestris | 2.2<br>2.0 | 14 to 28 days at 4 °C | Hartyáni, *et al* 2013 |
| Banana | Smoothie<br>N2-degassed | 550 MPa<br>2–10 min<br>20 °C | Total aerobic, Bacteria<br>Yeasts/Molds/ | 2<br>2.5 | more than 15 days at 4 °C | Li *et al*, 2015 |
| Orange | Juice | 700 Mpa, 5 min, 4 °C | S. aureus | 6.2–6.6 | 15 days at 4 °C. | Syed et *al*, 2014 |
| Sauerkraut | Fermented Cabbage | 300 MPa<br>10 min<br>40 °C | Total coliforms<br>Aerobic, Mesophilic, Bacteria<br>Lactic acid bacteria<br>Faecal coliforms<br>Yeasts/Mold/ | <1<br>4.2<br>4.2<br><1<br><1 | 60 days<br>4 °C | Penas *et al* 2010 |
| Sour Chinese Cabbage | Fresh | 400–600MPa<br>10–30 min | Total aerobic Bacteria<br>Lactic Acid Bacteria<br>Yeasts` | 2.7–4.5<br>2.4–4.3<br>1.5–2.0 | 60 days<br>4 °C | Li et *al*, 2010 |
| Tomato | Juice | 300–500 MPa10 min<br>25 °C | Viable microbial Cells<br>Yeasts/Molds/<br>Enterobacteria<br>Lactic acid, Bacteria | 0.9–4.1<br>3.7/3.6<br>2.1<br>4.2 | 28 days<br>4 °C | Heu *et al.*, 2008 |

**Effects of HPP on sensory properties of fruits and vegetables**

HPP was also reported as a promising preservation technique for fruit juices, and even improved its sensory properties relative to fruit juices preserved in the traditional way by heat treatment (Sharma *et al.*, 2020). Studies showed that HPP treatment of fruits and vegetables increases their different sensory acceptability parameters.

**Color**

Numerous studies have been conducted on the impact of HPP on the color of various fruit and vegetable products. HHP treatment (400–600 MPa, 5 min), combined with citric acid and pomelo essential oil nanoemulsion, preserved the quality attributes such as color and nutritional values of banana puree (Zou *et al*., 2023). Rodrigo *et al*. (2007) reported that maximum increase of 8.8% in *L, a, b* parameter for strawberry juice samples under combined thermal and high-pressure treatment (300–700 MPa, 65 °C, 60 minutes). However, there were no significant effects of HHP treatment on the color of Grape Puree (Li & Padilla-Zakour, 2021). Butz *et al*. (2003) also depicted that the ultra-high-pressure treatment of various fruit juices (oranges, apples, peaches, mixed citrus juices, carrots, tomatoes, and frozen raspberries) had no impacts on carotenoid content associated with the reference samples. The authors also confirmed that the color of tomato puree remained unchanged after high pressure treatment (up to 700 MPa) at 65 °C even for 1 hour. Therefore, the current reports indicated that HPP has minimal effects on the color of fruits and vegetables.

**Flavor**

A food's flavor is its overall sensory impression, mostly influenced by the chemical senses of taste and smell. The common consensus is that HPP does not affect the fresh flavor of fruits and vegetables since high pressure has no direct effect on the structure of low molecular flavor components (Oey *et al*., 2008). The findings reported by Zabetakis *et al*. (2000) demonstrated that following a day of cold storage at 4 °C, strawberries treated with pressure (200, 400, 600, or 800 MPa/18-22 °C/15 min) had lower concentrations of acids (butanoic acid, 2-methyl-butanoic acid, and hexanoic acid) and a ketone compound (2,4,6-heptanetrione) than the untreated strawberries. Dalmadi *et al*. (2007) conducted a study on the effects of heat pasteurization (80 °C, 5 min) and HHP treatment (600 MPa, 5 min, at ambient temperature) on the volatile composition of raspberry, strawberry, and blackcurrant purees. The findings showed that purees prepared under high pressure retain more flavor.

**Texture**

It has been demonstrated that pressure softens the texture of fruits and vegetables, and that cell wall collapse and turgidity loss can cause tissue firmness to be lost (De Belie, 2002). According to Trejo-Ayara *et al.* (2007), the primary source of textural alterations in raw carrots is the loss of turgidity resulting from fast compression and decompression. The impact of HPP (100-400 MPa/5-60 min/room temperature) on the hardness of several fruits and vegetables, including apple, pear, oranges, pineapple, carrot, celery, green pepper, and red pepper, was investigated by Basak and Ramaswamy (1998). The finding showed that a quick loss of hardness was noted during compression. Additionally, it was noted that applying pressure exceeding 200 MPa to certain fruits and vegetables for five to sixty minutes softened their texture. Tangwongchai *et al.* (2000) also confirmed that high pressure treatments on cherry tomato showed softening texture.

**Viscosity of fruits and vegetables**

Fruit and vegetable products' rheological characteristics are impacted by HPP application. The study conducted on the effects of HPP on viscosity of orange juice showed that pressure treatment (600 MPa/40 °C/4 minutes) resulted in a higher viscosity than thermal treatment (80 °C/ 60 seconds). Even at a high storage temperature (30 °C), the same report revealed that there is a slight drop in the viscosity of HP-treated juice during the storage (0, 5, 10, 15 or 30 °C for 64 days) (Polydera *et al*., 2005). There are reports in which the viscosity of mango pulp increased after HPP treatments at 100 or 200 MPa, whereas a reduction in viscosity was observed after HPP treatments at 300 and 400 (Gopal *et al.*, 2017).

**The effect of HPP on specific perishable products**

**Effects of HPP on meat**

**Nutritional composition**

Application of HPP preserved the qualities of meat and meat products and extended their shelf life by deactivating pathogenic and spoilage bacteria (Jofre, 2016). The effects on proximate and mineral compositions reported by Garriga *et al.* (2002) in Spain are summarized in Table 2. The study found that when HPP was applied for 10 minutes at 30 °C and 600 MPa, the moisture contents of cooked ham, dry-cured ham, and marinated beef loin decreased in comparison to the control. Protein contents of the marinated beef increased from 20.64% to 21.43%. However, protein content of both cooked ham and dry cured ham were decreased from 22.67% to 20.64% and 30.56% to 29.88%, respectively (Table 2). The effects might be due to protein found in cooked and dry cured ham denatured by heat and sunlight. Crude fat contents of pressured meat of marinated beef were lower than the non-pressured. However, the fat contents of pressurized cooked and dry cured increases as compared to the control. Regarding ash contents, all of the three products increased as compared to the non-pressurized samples. Furthermore, there is little effect on the carbohydrate contents of cooked ham as compared to the control. However, the carbohydrate contents of pressurized dry cured ham increase as related to non-pressurized (Garriga *et al*., 2002). Generally, these reports showed that HPP did not show a significant influence on the proximate composition of cooked ham, dry cured ham, and marinated beef loin.

**Table 2:** Review of effects of HPP on the nutritional composition of pressurized meat products

| Proximate Comp | Marinated beef | | Cooked ham | | Dry cured ham | |
|---|---|---|---|---|---|---|
| | **Control** | **HPP** | **Control** | **HPP** | **Control** | **HPP** |
| M (%) | 74.11 | 73.78 | 75.20 | 74.02 | 50.64 | 50.17 |
| CP (%) | 20.64 | 21.43 | 22.67 | 20.64 | 30.56 | 29.88 |
| C. Fat (%) | 4.54 | 3.68 | 2.63 | 2.97 | 12.9 | 14.6 |
| T.ash (%) | 1.68 | 1.96 | 3.16 | 3.18 | 6.24 | 6.41 |
| CHO (%) | 0.71 | 0.65 | 0.52 | 0.52 | 0.19 | 0.22 |
| Ca (mg/g) | 69 | 69 | 98 | 75 | 180 | 203 |
| K (mg/g) | 3374 | 3701 | 2765 | 2536 | 5096 | 4656 |
| Mg (mg/g) | 213 | 230 | 167 | 184 | 278 | 252 |
| Na (mg/g) | 2533 | 3574 | 7472 | 7321 | 19 496 | 19 745 |
| Fe (mg/g) | 16.96 | 20.37 | 8.10 | 6.99 | 11.55 | 13.28 |
| Zn (mg/g) | 2.47 | 20.35 | 17.43 | 15.86 | 25.26 | 22.76 |

**Source:** Garriga *et al. (2002)*

The results reported by Garriga *et al*. (2002) indicated that HPP had no significant effect on the calcium content of the marinated beef. However, compared to the control, the pressurized dry-cured ham at 600 MPa had higher levels of calcium, sodium, and iron. On the other hand, potassium, magnesium, and Zinc in pressurized dry-cured ham decreased compared to the non-pressurized. Similarly, calcium, potassium, sodium, iron, and zinc contents of pressurized cooked ham decreased compared to the control. But magnesium, sodium, iron, and zinc contents of pressurized marinated beef increase related to the reference sample. Generally, the studies showed that HHP has little effect on the mineral contents of meat.

**Beef lipid oxidation**

One of the most important elements in the non-microbial deterioration of meat is oxidation (Guyon *et al.*, 2016). It has been reported that pressure levels in the 300–600 MPa range are essential for causing lipid oxidation in fresh meat, including poultry, beef, and pork, as well as in meat products (Bolumar *et al.*, 2021). This can result in notable alterations to the phospholipid and free fatty acid composition and lipid content (Fuentes *et al*., 2010; Huang *et al*., 2015). Bajovic *et al*. (2012) depicted that the use of HPP can enhance lipid oxidation by increasing iron accessibility from hem proteins and causing membrane disruption. According to Tume *et al.* (2010), lipid oxidation may become noticeable during refrigerated storage but is typically not noticeable right away following HPP. Studies also found that the rate of lipid oxidation was significantly increased for the samples treated at a pressure of 300 MPa and above (Ma *et al.*, 2020).

**Meat's microbiological safety**

Meat is a nutrient-dense food that acts as a favorable medium for the growth of common food-borne diseases and bacteria that cause meat to decay by the microorganisms due to its high-water activity. For this reason, selecting and utilizing appropriate preservation strategies for meat and its products is crucial (Aymerich *et al*., 2008). A range of food-borne diseases and spoilage microorganisms, including vegetative cells, yeasts, molds, and viruses, have been shown to be effectively inactivated by HPP food preservation method (Considine *et al*., 2008; Tonello, 2011).

The findings of Gill and Ramaswamy (2008) about the impact of HPP treatments at 600 MPa on the recovery of E. coli O157 from beef salami slices indicated in Table 3. The outcome shown that, there is no detection of E. coli O157 after sliced beef meat treatment of vacuum-packed RTE meats with HPP at 600 MPa with holding times of 3 to 9 minutes up to three days. However, the number of *E. coli* O157 increased from 6.30 logs CFU/g to 6.51 logs CFU/g compared to the control. After the sliced beef meat pressurized at 600 MPa for 0 to 9 minutes, decrease in the number E. coli 0157 from 6.91 to 1.95, 7.15 to 3.76, 7.31 to 3.84, and 6.71 to 3.89 logs CFU/g during storage for 7, 14, 21 and 28 days, respectively. This result implies that application of HPP at 600 Mpa for 3 to 9 minutes can significantly reduce the number of *E. coli* O157 during the 3 to 28 days preventing spoilage (Gill and Ramaswamy, 2008). Therefore, the findings indicated that HPP treatment could be effectively applied to reduce *E. coli* O157 growth on sliced RTE meats. the studies also indicated that sliced RTE meats could be treated with HPP to successfully lower the growth of E. coli O157.

**Table 3:** Effects of HPP on E. coli O157 from sliced beef

| Time in minute | ***E. coli* O157 (log CFU/g) recovered on different days at 600 MPa** | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 3 | 7 | 14 | 21 | 28 |
| *Control* | 6.30 | 6.51 | 6.91 | 7.15 | 7.31 | 6.71 |
| *3* | + | + | 4.06 | 5.03 | 7.02 | 5.06 |
| *6* | + | + | 1.10 | 4.51 | 4.41 | 4.32 |
| *9* | + | + | 1.95 | 3.76 | 3.84 | 3.89 |

**Source:** Gill and Ramaswamy (2008)

+The colony counts using the plating of 2 log CFU/g E. coli O157 were less than the detection limit.

**Meat's sensory qualities**

The study by Mor-Mur and Yuste (2003) compared the effects of pressure-treatment at 500 MPa for 5 min at a mild temperature (65 °C) of sausages with those treated with conventional heat pasteurization (80–85 °C for 40 min) on sensory properties such as color and texture. The outcome demonstrated that there was no significant change in color. The findings also showed that pressured sausages were less firm and more cohesive compared to heat-treated sausages. Additionally, because of their superior appearance, flavor, and texture, sensory panelists favored sausages treated with HPP samples (Mor-Mur and Yuste, 2003). To accomplish microbial inactivation, meat usually needs to be pressure-treated above 400 MPa; this pressure-induced protein denaturation results in meat that is discolored (Wackerbarth *et al*., 2009).

**Effects of HPP on the preservation of fish**

**Amino acid profile of fish fillets**

According to Balami *et al*. (2019), fish meat offers high-quality protein, polyunsaturated fatty acids (omega-3 and omega-6), and a range of minerals and vitamins that can help prevent or treat certain disorders. However, the fish fillet is highly perishable and there are limited techniques to prolong its shelf life beyond freezing; hence, the product quality may be low so that consumers will not accept. To overcome the problem, application of HPP may extend the shelf-life of seafood to maintain the fresh-like characteristics demanded by consumers (Yagiz *et al*., 2007). According to the study conducted by Kim *et al.* (2018), the effect of HPP on free amino acid of fish sauce is summarized in Table 4. According to the results, there is no difference in Aspartic acid and Asparagine contents of amino acid between pressurized and non-pressurized fish sauce. However, all of the amino acid profiles increase after pressure treatment.

**Table 4:** Impact of HPP on free amino acid contents (μmol/g) of fish sauces

| Amino acids | Treatments | |
|---|---|---|
| | **Non-HPP** | **HPP** |
| Aspartic acid | 10.3 | 10.3 |
| Glutamic acid | 33.3 | 40.0 |
| Glutamine | 6.0 | 6.8 |
| Asparagine | 1.2 | 1.2 |
| Glycine | 26.6 | 26.8 |
| Threonine | 12.0 | 16.5 |
| Alanine | 31.0 | 37.6 |
| Serine | 10.3 | 13 |
| Proline | 7.9 | 10.2 |
| Valine | 18.7 | 26.0 |
| Histidine | 6.4 | 8.3 |
| Leucine | 18.8 | 23.3 |
| Isoleucine | 13.3 | 16.9 |
| Arginine | 1.7 | 2.4 |
| Tryptophan | 7.4 | 7.8 |
| Lysine | 27.4 | 48.8 |
| Tyrosine | 2.1 | 2.3 |
| Phenylalanine | 10.2 | 11.7 |
| Methionine | 6.3 | 8.7 |

**Source:** *Kim et al., 2018*

**Microbial quality of fish fillets**

The application of HPP might provide a solution for the preservation of fish salad with mayonnaise. A few minutes of HP treatment at 300 MPa or higher level significantly reduces the initial load and/or growth rate of spoilage microorganisms and enzymatic activity in many fish products stored under chilled conditions (Erkan *et al*., 2010). Mengden *et al*. (2015) reported that HPP treatment for five minutes at 400 or 600 MPa, the spoilage microbiota in mildly smoked rainbow trout fillets was low (approximately 1-2 log CFU $g^{-1}$) throughout 41 days of storage. It was also reported that with HP treatment (200-400 MPa) can effectively avoid microbial growth, trimethylamine development, and autolytic activity in sliced raw squids, therefore, increasing its shelf life (Jolvis Pou, 2021).

**Shelf life of fish filets**

The effects of HPP at 200 MPa for 15 minutes at 5 °C on the shelf life of freshwater rainbow trout were documented by Gunlu *et al*. (2014). The findings showed that when fish fillet was kept at 4±1 °C, its shelf life was increased by up to 4 days (Table 5). Karim *et al*. (2011) conducted a study on the shelf life of herring (small commercial fish) by comparing non-pressurized samples with those treated with high pressure, such as 200 MPa, 250 MPa, or 300 MPa, for 1 or 2 minutes at 2 °C. The results depicted that fish filles treated with high pressure increased from 11 to 18 days while non-pressured fish fillet stayed for only 6 days. Furthermore, Erkan *et al*. (2011) showed that the high-pressure treatment on cold smoked salmon (sea fish) at 250 MPa, 3 °C for 5 minutes , and 250 MPa, 25 °C for 10 minutes indicated that the shelf life extended up to 8 weeks while non-pressurized sample stayed 6 weeks. Moreover, the study reported by Erkan and Uretener (2010) highlighted those treatments of high pressure at 250 MPa for 3 min at 5 °C, and 250 MPa for 3 min at 15°C increased the shelf life of fish for 18 days, and the control sample stayed only for 16 days. These scientific reports indicated that the combination of HPP and smoking can extend the shelf life of fish fillets to two months.

**Table 5:** Effects of HPP on microbial quality and shelf life of Fish fillets

| Types of sea food | HPP | Shelf life | References |
|---|---|---|---|
| Rainbow trout (freshwater fish) | In combination with vacuum packaging 220 MPa for 15 min at 5 °C, kept in chilled (4±1 °C) | 4 days | *Gunlu et al., 2014* |
| Herring (small commercial fish) | Control | 6 days | *Karim et al., 2011* |
| | 200 MPa for 1 min at 2 °C | 11 days | |
| | 200 MPa for 3 min at 2 °C | 17 days | |
| | 250 MPa for 1 min at 2 °C | 13 days | |
| | 250 MPa for 3 min at 2 °C | 16 days | |
| | 300 MPa for 1 min at 2 °C | 18 days | |
| | 300 MPa for 3 min at 2 °C | 16 days | |
| Cold smoked salmon (sea fish) | Control | 6 weeks | *Erkan et al., 2011* |
| | 250 MPa, 3 °C for 5 min and | 8 weeks | |
| | 250 MPa, 25 °C for 10 min | 8 weeks | |
| Sea beam (ocean fish) | Control | 15 days | *Erkan and Üretener, 2010* |
| | 250 MPa for 3 min and 5 °C | 18 days | |
| | 250 MPa for 3 min and 15 °C | 18 days | |

**Sensory properties of Fish fillets**

The study conducted on the effects of HPP on the sensory properties of fish fillets by Rodrigues *et al*. (2011) indicated that sensory properties such as appearance, odor, taste, and texture did not change with HPP below 500 MPa. The study also demonstrated that because flavor, texture, and appearance were impacted by the pressure at these levels, panelists did not favor the samples treated with 500 MPa and 600 MPa. Samples treated between 100 and 300 MPa had the best treatments concerning taste, texture and appearance. In addition, the studies treated Coho salmon at four different pressures. After comparing the sensory qualities of the treatments at 170 MPa and 200 MPa, the treatment at 135 MPa for 30 seconds was the most tolerable. Furthermore, it was confirmed by Yagiz *et al*. (2007) that fish fillets treated with HPP at 150 to 450 MPa maintain their color.

**Effects of HPP on dairy foods**

**Milk**

Milk, as being a functional perishable food, is generally subjected to heat treatment to attain a safe and acceptable shelf life. However, heat could be destructive to natural nutrients and bioactive compounds (Chawla *et al*., 2011). The primary issues encountered with the conventional processes of pasteurization, sterilization, and concentration of milk are the undesirable organoleptic qualities that are lost, particularly those associated with texture, color, and flavor. Besides sensory qualities, a significant loss of polyunsaturated fatty acids and vitamin B complex, as well as changes to the degradation of milk proteins were reported by different scholars (Deeth, 2020; Pegu & Arya, 2023; Abramovich *et al*., 2013). The development of an unpleasant taste and smell was also noted because of the Maillard reactions that produced Amadori compounds and sulfhydryl compounds. As a result, a lot of research has been done on the application of substitute preservation techniques to guarantee the security and caliber of milk and dairy products.

Different studies suggested innovative processing techniques, such as non-thermal processing, such as HPP, to address the issue. For example, Shabbir *et al*. (2012) looked into how HPP affected E. coli, Shigella, Salmonella, and Staphylococcus aureus in raw milk. The findings showed that the best conditions for inactivating Salmonella, E. Coli, Shigella, and S. aureus were 300 MPa treatment for 30 minutes at 25 °C. Additionally, Vachon *et al*. (2002) reported employing high pressure (100, 200, and 300 MPa) to inactivate pathogenic microorganisms in milk, including Salmonella enterica serotype, E. coli, and Listeria monocytogenes. The researchers discovered that HPP has been demonstrated to be highly effective in destroying pathogens found in milk.

**Cheese**

Evert-Arriagada *et al*. (2014) investigated how fresh cheeses without starters fared in cold storage for 21 days under pressure of 500 MPa for 5 minutes at 16 °C. The result showed that, when kept at 4 °C, pressured cheeses had a shelf life of roughly 19–21 days, while control cheese only stayed for 7-8 days. Furthermore, Voigt *et al*. (2012) observed the ripening of cheddar cheese made from raw milk (control) and milk that had been HP-treated for 10 minutes at 20 °C at 400 MPa or 600 MPa. It was reported that after HP-treating the milk at 600 MP, the numbers of non-starter lactic acid bacteria (NSLAB) were much lower. The microbial load in Cheddar cheese was significantly decreased by the application of HP; 400 MPa for 20 minutes at 20 °C was found to be adequate to decrease the number of viable E. coli, P. roqueforti, and S. aureus by 7, 6, and 3-log unit cycles, respectively (Rastogi, 2013). This study reported that for the cheese samples made from raw and pasteurized milk, HP treatment completely reduced the counts of molds, yeasts, and Enterobacteriaceae. The level of L. monocytogenes in raw milk was also dramatically decreased by the HP-treatment (500 MPa, 10 min), which made it possible to produce a safer non-thermally processed soft cheese similar to camembert. According to Evert-Arriagada *et al*. (2012), cheese that was held at 4 °C and treated at 300 and 400 MPa had a shelf life of 14 and 21 days, respectively, while the untreated cheese only had a shelf life of 7 days. The outcomes demonstrated that the cheese's shelf life might be extended by HP treatment.

**Yogurt**

Yogurt is typically semi-solid and in smallholder dairy farms it is produced from whole milk. Gebeyew *et al. (*2016) reported that the mean shelf life of the yoghurt is only 4 days at room temperature. Thus, the application of HPP is crucial to maintaining the nutritional values, and sensory qualities, and extending the shelf life of yoghurt. Dhineshkumar *et al.* (2016) and Rastogi (2013) determined the effects of HPP on the shelf life of yogurt at 550 MPa and stored for 4 weeks at refrigerated (4 °C) or room (20 °C) temperature. The findings highlighted that pressure treatment prevented post acidification of the product and the bacterial counts in the HP-treated yogurt stored at 4 °C was maintained at less than the minimum level of $10^6$ CFU/mL. The authors also reported that no microbial spoilage took place in the HP-processed sample even after

60 days of storage at 4 °C and 20 °C. In addition, the count of LAB was decreased to <10 CFU/mL. Additionally, researchers found that applying high pressure during the initial processing of milk used to make yoghurt enhanced the curd's hardness and reduced its syneresis (Sfakianakis & Tzia, 2014; Liepa *et al*., 2016). In general, the manufacturing of high-quality yoghurt might benefit greatly from the application of HPP technology.

## CONCLUSION

In this paper, the potential of HPP for the preservation of nutritional values, microbial safety, and sensory property of perishable food products, such as fruits, vegetables, meat, fish, milk, cheeses, and yoghurt, was reviewed. The application of HPP treatments from 400 to 600 MPa maintains Sensory properties, low microbial count, and extended shelf life of fruits and vegetables. In addition, HPP treatments from 100 to 400 MPa is effective to preserve perishable animal products such as meat, fish, milk, cheeses, and yoghurt through the destruction of pathogenic microorganisms, maintain sensory properties and increases shelf life. The examined data from different literatures also showed` that commercially available HPP rendered the majority of hazardous and spoilage bacteria inactive when processed of perishable agricultural products forshort periods at ambient temperature and pressure ranges between 400 MPa and 600 MPa. Generally, HPP can minimize or completely eliminate the need for chemical preservatives while maintaining nutritional quality, reducing processing times, uniformly treating packages, and effectively eliminating vegetative germs and spores without producing any harm in perishable animal and plant products. However, information related to the effect of HPP on the possibility of toxicity of processed foods or associated allergens. Therefore, the application of HPP in processing perishable fresh agricultural food products would substantially extend their shelf life, improve acceptability, and maintain nutritional values.

### CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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