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Recent Advances in Food Processing Using High Hydrostatic Pressure Technology

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High hydrostatic pressure is an emerging non-thermal technology that can achieve the same standards of food safety as those of heat pasteurization and meet consumer requirements for fresher tasting, minimally processed foods. Applying high-pressure processing can inactivate pathogenic and spoilage microorganisms and enzymes, as well as modify structures with little or no effects on the nutritional and sensory quality of foods. The U.S. Food and Drug Administration (FDA) and the U.S. Department of Agriculture (USDA) have approved the use of high-pressure processing (HPP), which is a reliable technological alternative to conventional heat pasteurization in food-processing procedures. This paper presents the current applications of HPP in processing fruits, vegetables, meats, seafood, dairy, and egg products; such applications include the combination of pressure and biopreservation to generate specific characteristics in certain products. In addition, this paper describes recent findings on the microbiological, chemical, and molecular aspects of HPP technology used in commercial and research applications.

Keywords Food processing, high hydrostatic pressure, non-thermal technology, pasteurization

1. *INTRODUCTION*

The Center for Disease Control and Prevention (CDC) estimates that food-borne diseases cause approximately 70 million illnesses, 300,000 hospitalizations, and 5000 deaths in the United States each year (http://www.cdc.gov/). Experts from the food industry have been endeavored to improve food-processing methods to eliminate infections caused by microorganisms and to ensure that the flavor, color, taste, and form of foods remain unchanged. Food safety and shelf life are often closely related to microbial quality and other phenomena, such as biochemical reactions, enzymatic reactions, and structural changes, which can indirectly significantly influence the perception of consumers regarding food quality. Conventional thermal pasteurization processes of food preservation involve transferring heat from a processing medium to the slowest heating zone of a product, which is subsequently cooled. Therefore, although thermal processes are effective mechanisms for microbial inactivation, they occasionally permit changes in product quality and cause off-flavor generation, textural softening, and the destruction of colors and vitamins. The extent of such changes depends on the product being treated and the temperature gradients between the food and the process boundaries involved (Norton and Sun, 2008). However, a recent increase in demand has presented challenges to the food industry, mainly in implementing techniques to preserve the freshness of foods for longer periods, in offering a reasonable shelf life and convenience, and in ensuring food safety. Consumer demand for minimally processed foods has created interest in non-thermal technologies, such as HPP, intense pulsed light, pulsed electric field, irradiation, and ultrasound (Caminiti et al., 2011; Geveke and Torres, 2012; Awad, et al., 2012). Therefore, non-thermal processes are being developed as an alternative to traditional thermal methods, which can be defined as those in which temperature is not the main factor in the inactivation of microorganisms and enzymes. These technologies are used to inactivate of food-borne pathogens and certain enzymes of interest without destroying the nutritional and sensory components that are usually affected during heat treatment. HPP is considered one of the most promising non-thermal food preservation techniques and is used for commercial pasteurization of an increasing number of food products. HPP involves using liquids

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(water is the usual pressure transmission medium) to convey pressure at 100–800 MPa (generally no less than 100 MPa) to treat food materials; most pressure levels used in commercial applications range from 200 to 600 MPa, depending on the product (Mújica-Paz et al., 2011). Previous studies have investigated HPP for a wide range of applications, including non-thermal decontamination of acidic foods, combined pressure-heating treatments to inactivate pathogenic bacteria and enzyme deactivation, and the production of new materials. For example, the packaged food, usually under vacuum in a flexible package, is placed in a pressure vessel containing a pressure-transmitting liquid. The pressure is produced by a hydraulic pump or a piston and is isostatically transmitted inside the pressure vessel to the food product instantaneously and uniformly. The food product undergoes the process of food processing under static high pressure and certain temperatures for an appropriate period to activate the destruction or formation of non-covalent bonds of food components, such as hydrogen bonds, electrovalent bonds, and hydrophobic bonds, to deactivate, denature, and gelatinize the enzymes, protein, and starch, and destroy pathogenic bacteria and microorganisms in the food. Therefore, the objectives of food pasteurization, preservation, and processing are involved in this process. (Bermúdez-Aguirre and Barbosa-Cánovas, 2011).

High-pressure technology is used in a numerous of countries, including the United States, Mexico, South Korea, Spain, and Japan, with sales rapidly increasing annually by US $10 billion. The number of high-pressure units has been growing exponentially at an annual rate around the world and used mostly in America region (Figure 1). This technology has been approved by the U.S. FDA and the USDA for application in food processing procedures. Therefore, the National Advisory Committee on Microbiological Criteria for Foods (NACMCF) has recommended redefining pasteurization, and HPP is listed as a supplementary non-thermal pasteurization technique (Barbosa-Cánovas and Juliano, 2008). Under non-thermal conditions or without the addition of preservatives, HPP can ensure the safety of any food and substantially prolong the cold-storage period of food considerably. Hence, HPP can eliminate pathogenic bacteria to preserve the flavor, color, quality, and nutrients of processed food, enhance the safety and edibility of any food, and lengthen the expiry date. This technology has been applied to various agricultural products and sideline items. In the future, developing high-pressure research in the food industry and applying HPP are expected to revolutionize the eating habits and everyday life of humans.

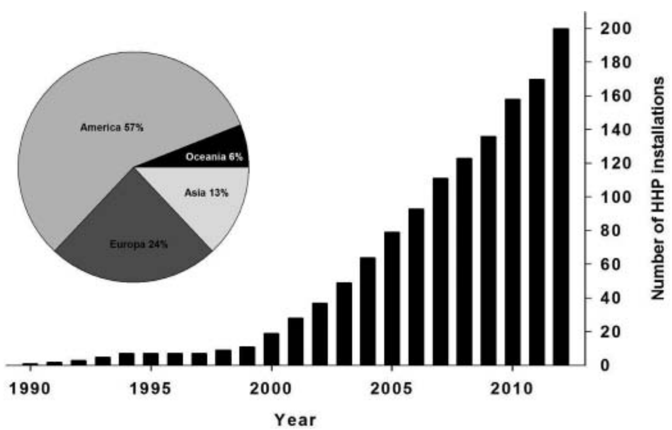

Figure 1 Development and increase in number of HPP installations in the world. Source: NC Hyperbaric, Burgos, Spain (www.nchyperbaric.com).

2. *PRINCIPLES OF HPP TECHNOLOGY*

Food is a 3D structure of various substances comprising of protein, starch, lipids, enzymes, nucleic acid, and liquid.

At high pressure, the gaps of micro molecules (e.g., water molecules) of the food became narrow, whereas substances consisting of larger molecules, such as those in protein, remain spherical. Small molecules produce the effects of permeation and filling, and adhere to the surroundings inside larger molecules, such as those in protein. Larger molecule chains, such as protein chains, are lengthened after the UHP decreases to a normal pressure. This lengthening is caused by the alteration of the processing pressure, which suggests a part or whole destruction of the 3D structures of larger molecule chains, thus changing the protein structure or deactivating the structure of the enzyme (Rivalain et al., 2010). Pressure-treated proteins retain their primary structure because covalent bonds are unaffected by pressure. The main contribution of pressure to enzyme inactivation is the structural rearrangements of proteins under high pressure, such as hydration changes that accompany other intramolecular non-covalent interactions. High pressure can damage the organization of any microorganism and causes other molecules to enter the membrane of the microorganism, resulting in pasteurization through destruction of the structure of the microorganism membrane. Protein is one of the main components of microorganisms. HPP inactivates microorganisms by interrupting the cellular functions responsible for reproduction and survival. HPP can damage microbial membranes, thus affecting the transport phenomena in nutrients and the disposal of cell waste. Cell functions are altered when crucial enzymes are inactivated or membrane selectivity is disabled. HPP causes changes in membrane structures that result in microbial inactivation effects; however, they can also facilitate the access of an enzyme to its substrate, thus causing product deterioration during storage. Changes in the structure of crucial macromolecules, such as deoxyribonucleic acid and proteins with enzymatic activity, also contribute to food preservation. In addition, the liquid, sugar amount, concentration of salt ions, pH value, and components of the food or processed food products are involved in the reproduction of the microorganism. The effect of preservation can be improved if high pressure is combined with the pH value, temperatures, chemical additives, or modified atmosphere packaging of a product (Rendueles et al., 2011).

HPP applies to all types of liquid and solid food products, especially foods that are sensitive to heat and highly acidic food products that are adverse to the growth of spores. Additionally, the pressure of 600 MPa can deactivate most vegetative bacteria (except spores), help preserve the quality and natural flavors of food products, and prolong the expiry date of food products, thus expanding the scope of sales and markets for semi-products. Food products that have undergone HPP do not require chemical additives and can expel the unacceptable chemical reagents to ensure the safety of the food. Under general conditions, the extermination of parasites is similar to that of other living organisms; that is, parasites can be eradicated at a relatively low pressure. Viruses can be deactivated at a lower pressure, and bacteria, fungi, and yeast can be destroyed at 600 MPa (Kovac et al., 2010). High pressure can be more easily controlled and is less affected by external surroundings. Conversely, traditional sterilization techniques that entail using chemical reagents can be influenced by factors such as moisture, temperature, pH value, and the organic environment, and their effects are less predictive. In addition, frequent use of chemical reagents may lead to the resistance of microorganisms, thereby weakening the effects of sterilization.

The raw materials of food products of which HPP can be applied are categorized into 2 types:

2.1. *Liquid Food*

By using high pressure pumps, raw materials of food products are conveyed to high-pressure containers, and undergo increased pressure until the pressure indicator is reached. This state is maintained for a certain period before decreasing the pressure, delivering the items, and working with sterilized packaging according to the requirement of the product. A product is produced in this manner. This is the intermittent type of HPP; continual HPP delivers raw materials with pumps in a continuous fashion through a pressured system to produce the product (Chawla et al., 2011).

2.2. *Solid and Semisolid Foods*

Raw materials that have been processed in advance (such as jams or pulps) undergo the process of vacuum soft packaging before being transferred into high-pressure, tightly sealed containers, and pressed with pumps for a prolonged period. The pressure is decreased after the pressure process is complete; subsequently, the lid is opened, the packaging is removed, and the product is finished. This method places a high standard on containers; that is, fast sealing is strictly required in the process of placing and retrieving raw materials, and the container must be equipped with devices with wide openings for quick retrieval to facilitate the conveyance of raw materials (Barrett and Lloyd, 2012).

3. *CHARACTERISTICS OF HPP*

Traditional food processing includes thermal sterilization or canned methods. A disadvantage of the heat sterilization process is that it alters the taste, flavor, and other characteristics unique to the food and destroys nutrients such as vitamins. Scientists have striven to develop superior food-processing methods, including research and development of chemical preservation, irradiation preservation, and high-pressure processing, among which HPP is considered the processing method with the highest potential to preserve the original forms of food products (Mújica-Paz et al., 2011). HPP has numerous other features, which are described in the following subsections.

3.1. *Pasteurization and Sterilization*

High pressures of 300–700 MPa can destroy bacteria; however, it cannot completely destroy spores. Pressure works in a manner that activates spores to sprout and lose their ability to resist heat and pressure. Methods that combines pressure (600 MPa) and heat (60–90°C), as well as the pressure circulation method (100–600 MPa), can eradicate large amounts of microorganisms, with the exception that particular microorganic spores are inclined to resist pressure (Demazeau and Rivalain, 2011). Therefore, to predict the storage period of food products precisely, a large quantity of reliable basic data is required to serve as a reference when pressure sterilizing food products on a large scale.

3.2. *Maintaining Nutritional Value and Quality of Foods*

Thermal processing can often lead to quality changes in foods, such as the destruction of vitamins, modifications to food texture and color, and the development of off-flavors. High-pressure operations can render harmful microorganisms inactive without detrimentally affecting the color, flavor, or nutritional value, thus improving the overall quality of foods. HPP enhances reactions that are associated with volume compression. Because the change in volume after the breaking of covalent bonds is small, its effects on low-molecular mass compounds, such as vitamins, flavones, and phenol, are expected to be limited (Oey et al., 2008). Most of the original nutrients are preserved in food products that undergo HPP, and can be easily digested by humans. Cilla et al. (2011) found that HPP positively modulates Ca and P bioavailability, in contrast to thermal treatment in a cell model system. Conversely, traditional thermal methods or a high-temperature short-time (HTST) method, which involves squeezing and extrusion, may destroy the nutrition of food products to various extents. HPP can be used to manufacture natural, minimally processed, or chemical additive-free foods by, for example, reducing the salt in smoked dry-cured ham without compromising the safety or overall quality (Stollewerk et al., 2012). In additional, HPP can be useful in improving the extraction of potentially health-related compounds because of its extract effect as an alternative to the heat extraction of foods with heat-sensitive properties (Zhang et al., 2004). Al-Habsi and Niranjan (2012) compared the effects of HPP and thermal treatments on the antimicrobial activity of Manuka honey. The antimicrobial effect can be enhanced using HPP without adversely affecting the quality of the honey.

3.3. Maintaining Food Flavor and Color

HPP has a limited effect on low-molecular-weight flavors and color compounds of food products, and can inactivate enzymes. In addition, HPP can alleviate the Maillard reaction caused by the components of food and eliminate disadvantages, such as color change and odors from heating, by using traditional thermal pasteurization technology (Schwarzenbolz et al., 2002). The flavors of common foods are altered after reheating; however, HPP can achieve sterilization and preserve the original fresh flavor of foods. Hence, HPP can be used to manufacture ready-to-use packaged food or frozen prepared food because an HPP food product retains fresh flavor of raw material to the greatest extent and can maintain its high quality and original flavor after reheating.

3.4. High-pressure Shift Freezing

High-pressure shift freezing has been proposed as a method to produce frozen food with smaller ice crystals, reduced tissular damage, and high overall quality. The freezing point of water is reduced at elevated pressure, and food that has been allowed to super-cool under pressure (approximately $-20°C$ at 210 MPa) undergoes rapid freezing once atmospheric pressure is restored. Pressure shift freezing induces the formation of smaller ice crystals and results in less physical damage to the food structure; thus, pressure mounting can enable food to be stored below 0°C and prevents problems caused by icing. Quick freezing is a method of forming tiny ice crystals within a structure with quicker transmission through the largest iced-crystal belt to decrease freezing stress and elevate the quality of freezing. Because heat resistance occurs in the process of freezing, phase transitions cannot be completed instantly and formed ice crystals tend to be larger, thus irreversibly damaging or denaturing the structure. This phenomenon may also occur in the commonly used $-30°C$ quick freezing method. Therefore, HPP freezing involves applying the fundamental theories of decrease of ice point and instant transmission of pressure. The damaging and denaturing states can be alleviated by pressing the high-moisture raw material at 200 MPa and allowing it to cool to $-20°C$, at which point the temperature is higher than the freezing point and no freezing occurs, followed by reducing the pressure to the normal state. When the freezing point becomes 0°C and $-20°C$ water turns into an unstable super-cooled state, and produces a large amount of tiny ice crystals that are distributed over the structure of the iced item. Pressure-assisted thawing has the advantage of inducing a reduction in drip loss, which tends to be a function of process parameters and the nature of the product. Pressure shift freezing permits preservation of the microstructure of biological substances. However, the expenditure required under a long-time high-pressure condition is another concern (Volkert et al., 2012). Fernandez et al. (2007) evaluated conventional freezing and high-pressure low-temperature treatment on the physical properties, microbial quality, and storage of fresh and salt-added beef loins. The results showed that freezing protects meat from the detrimental effects of pressure on color, with meat returning to its original color after thawing, indicating that it can be marketed as refrigerated without consumer rejection. Realini et al. (2011) indicated that HPP combined with low freezing temperature can be used successfully to deliver long-lasting and high-quality pork with an extended shelf life to the ready-to-eat market.

3.5. Extending Product Shelf-life

Consumers demand safe, minimally processed, additive-free, shelf-stable foods that retain their natural appearance, flavor, texture, and nutritional qualities; however, some fresh foods such as fish, meat, and dairy products, have neutral pH levels and high water activity (>0.9), and are characterized by a short shelf life. Inactivation of food spoilage microorganisms and enzymes using HPP has been extensively demonstrated to improve food safety and increase the shelf life of food products. Kaur et al., (2012) reported that HPP treatment induced a hardening effect in fresh shrimp, which exhibited an extended shelf life of 15 days at 435 MPa compared with five days in untreated shrimp. The treated shrimp maintained lower viable counts throughout the storage period; thus, their microbial quality was superior to that of the untreated sample. Liu et al., (2012) evaluated the combined effect of HPP and enterocin on the shelf life of ready-to-eat sliced cooked ham. From a microbiological and physicochemical perspective, the most effective treatment was achieved by combining 400 MPa HPP and enterocin, which extended the shelf life to over 90 days and produced a superior sensory profile during the entire storage period. However, treatments of 200 MPa HPP and enterocin did not have an effect on physicochemical or sensory characteristics, and the final product possessed had a comparatively short shelf life. Evert-Arriagada et al. (2012) also observed that cheese treated at 300 and 400 MPa and stored at 4°C had a shelf-life of 14 and 21 days, respectively, compared to untreated control cheese, which had a shelf life of seven days.

3.6. Improving Food Quality and Values

Most HPP process applications in food systems have focused on shelf-life extension associated with non-thermal pasteurization and a reduction or increase in enzymatic activity. The original nutrition of HPP food can be preserved, and the organoleptic quality of such foods can be improved. The qualities of HPP products includes superior nutritional retention, fresh-like flavor, improved color, texture, and taste, and extended shelf life compared to thermally pasteurized products. Recent studies have use HPP in starch chemical modification to facilitate the derivatization of starch granules with chemical reagents in a non-thermal state and to modify the physicochemical properties of starch granule derivatives. The HPP-treated starch, which maintains an intact granular form and has partially and completely gelatinized granule interiors, may have excellent potential for use as a carrier to protect and/or transport nutrients. HPP-assisted reactions to various starch sources are required prior to the commercialization of UHP-assisted starch modification reactions (Kim et al., 2012a, b). Simonin et al., (2012) indicated various benefits of HPP on meat and meat products, such as modulating the texture and water retention, reducing the formation of biogenic amines, and improving hardness. Extensive research on HPP has created new opportunities to improve the balance between the safety and quality of current food products. In fruit and vegetable products, the nutritional content largely depends on the applied processing intensity; thermal sterilization affects nutritional quality the most, whereas mild and severe HPP pasteurization and HPP sterilization results in a comparable overall quality. Optimizing pressure-time conditions after HPP is crucial because it is possible to achieve microbial inactivation by applying high pressure at lower temperatures and for shorter treatment times than for those commonly used in thermal preservation, thus allowing superior retention of bioactive compounds and physicochemical characteristics (Barba et al., 2012).

3.7. Energy Saving

The main cost involved is the equipment and its installation; however, because of the current availability of high-pressure equipment, the cost of products processed using this technology has decreased considerably in recent years, making more products accessible to consumers. HPP is applied uniformly and instantaneously through food material, and can be transmitted in all directions within the shortest period and convey the pressure to the central point of the food, whereas traditional thermal processing requires a longer period to transmit heat. Regarding energy consumption, a small amount of energy is required to compress a solid or liquid to 500 MPa, compared to heating to 100°C (Pereira and Vicente, 2010). The average cost of HPP is approximately US\$0.05–0.5 per liter or kilogram depending on the processing conditions, and is lower than the cost of thermal processing (Bermúdez-Aguirre and Barbosa-Cánovas, 2011).

3.8. Environmentally Friendly Process

HPP is solely based on physics, and conducts pressure instantly, functions evenly, can be operated safely, and consumes relatively lower energy; thus, it contributes to the protection of the ecological environment. Because this type of processing has a shorter production period and uses simpler technologies, the chances of contamination are reduced and a numerous new types of food products can be produced. Moreover, during the HPP process, foods are not in direct contact with high-pressure equipment when packaged, therefore, the equipment dose not cause pollution, and reduces the use of chemical cleaning agents and environmental pollution. Moreover, HPP application is considered to be a waste-free process. The pre-sterilization of packaging using H_2O_2 or other chemical agents is not required, thereby contributing to a reduction in the amount of chemicals in liquid effluents (Pereira and Vicente, 2010). Although the investment capital of HPP is higher than those of traditional processing methods, this new technology can prolong the storage period of all food products, enhance the quality and value of food products, decrease the use of chemical additives and preservatives and make food products fresher. Thus, superior brands are created and more confidence is gained from consumers.

4. APPLICATION OF HIGH PRESSURE IN FOOD PROCESSING

The potential of high pressure to inactivate food pathogens and preserve most of the sensory, nutritional, and functional properties of treated products is beneficial to the food industry. HPP is a promising technology, and industrial HPP applications have grown rapidly, especially in stabilizing ready-to-eat meats and cured products. The evolution of HPP began in 1899, when American scientist Hite discovered that the high pressure of 450 MPa can lengthen the storage period of milk. In 1914, an American physicist claimed that egg whites can be solidified under 500 MPa pressure, and may form a layer of hard gel under the pressure of 700 MPa. In 1991, Japan produced the first food product under high pressure jam. In 1992, Fujichiku, a Japanese firm, produced the first meat product, pork ham, which was manufactured at 250 MPa and 20°C within three hours, equivalent to the item previously produced through pickling for two weeks (Demazeau and Rivalain, 2011). The softness, moisture retention, and preservation were enhanced, whereas the degree of saltiness decreased. The United States, Brazil, South Korea, and European countries have since conducted in-depth research and distributed food products in various markets. The following subsections describe how HPP has been applied in all sectors of the food industry.

4.1. Fruit- and Vegetable-derived Products

The quality of fruit and vegetable products includes superior nutritional retention, fresh-like flavor, improved color, texture, and taste, and extended shelf life, as compared to thermally pasteurized products. Several applications of HPP are currently used to process fruits, vegetables, and plant-based products, including the intelligent combination of pressure, temperature, and time to generate specific characteristics in certain products. The increasing demand for healthy foods with less physical damage and environmentally friendly processing provides new opportunities for the hurdle-technology concept of food preservation. HPP can preserve nutritional value and the delicate sensory properties of fruits and vegetables because of its limited effect on the covalent bonds of low molecular-mass compounds, such as those involving color and flavor compounds. During HPP, various pressure and temperature combinations can be used to achieve the desired effects on the texture, color, and flavor of foods. However, the quality of high-pressure processed fruits and vegetables can change during storage because of coexisting chemical reactions, such as oxidation and biochemical reactions when endogenous enzymes or microorganisms are incompletely inactivated. A recent study by Vega-Gálvez et al. (2012) indicated that the parenchyma of *Aloe vera* contains a transparent mucilaginous jelly, which is a traditional medicinal material used in the food, pharmaceutical, and cosmetic industries. To extend shelf life, it is crucial to maintain almost all of the bioactive chemical entities that are naturally present in the *A. vera*. The authors found that a 500-MPa/5 minutes pressure treatment can preserve the most relevant quality attributes of *A. vera* gel, including microbiological, nutritional, and antioxidant aspects, without affecting the physicochemical quality at intervals of up to 60 days. In several plant-based products, HPP has little to no influence on nutrimental composition or flavor, and controls the enzyme activity. Verbeyst et al. (2012) investigated thermal and HPP for their effects on bioactive compounds by treating strawberries and raspberries at various temperature-pressure combinations. HPP (400, 600, and 700 MPa at 20, 50, 80, and 110°C) did not have a substantial effect on the bioactive compounds. The breakdown of anthocyanins and vitamin C occurred at a constant elevated pressure as the temperature increased. No clear trends were observed for the amount of phenolic substances during processing. Velázquez-Estrada et al. (2012) found that high-pressure homogenization treatments are effective in controlling the pectin methylesterase activity and spoilage bacteria of orange juice. Treatments at 200 MPa, which entail pre-warming the samples at 20°C, and treatments at 300 MPa are excellent alternatives to thermal pasteurization. Calligaris et al. (2012) also reported that these treatments are a reliable technological alternative to conventional heat treatments for the production of fresh-like banana juice. The treatment of banana juice at 200 MPa allows a 4 four log cycle of mesophilic bacteria reduction as well as pectate lyase inactivation. Pomegranate juice was also studied under high pressure because of its high amount of bioactive compounds; processing pressures (350–550 MPa for 30, 90, and 150 s) on microbial quality and physicochemical and bioactive compounds were tested to determine the optimal processing conditions. Neither the pH, °Brix nor titratable acid were substantially affected by HPP for the first 15 days. The color stability of pomegranate juice depends on the HPP conditions. HPP treatment at or above 350 MPa for 150 s was sufficient to reduce the spoilage microorganism naturally present in pomegranate juice to undetected levels, thus extending the microbiological shelf life for more than 35 days during refrigerated storage at 4°C (Varela-Santos et al., 2012). Most research results have confirmed that pressure, pH value, and temperature are crucial factors that affect HPP and deactivate enzymes. The current fruit and vegetable products that have undergone HPP include salsa, pre-chopped vegetables, organic juices, smoothies, and jams. Some fruits and vegetables can reach a high-quality standard of color, freshness, taste, and food safety only through high-pressure treatments, therefore, larger quantities of fruits and vegetables are expected to appear in supermarkets, restaurants, and households in the future. Some of the important finding in this area has been summarized in Table 1.

4.2. Egg Products

Whole liquid eggs or blended liquid egg products are used in several food products because of their nutritional value, and contribute physicochemical properties to foods, such as coagulating, foaming, and emulsifying. Microbial inactivation, texture, sensorial quality, physicochemical parameters, and storage life are a few of the tested characteristics after pressurizing these products. Therefore, alternatives to this conventional processing, such as HPP applications, are being explored to extend shelf life and prevent the disadvantages of the pasteurization process. The benefits of HPP in egg compounds include improving of the foaming capacity of egg whites because of exposure of the SH groups, which improves foaming stability and capacity (Yang et al., 2009; Van Der Plancken, et al., 2007). In studies on the microbial inactivation liquid whole eggs using HPP, applying low-intensity treatments of HPP (300 MPa/3 min) followed by heat (52°C/3.5 min or 55°C/2 min) in the presence of 2% triethyl citrate offers the same microbial safety level as that of liquid whole eggs industrially treated at 71°C/1.5 min, but with quality levels of properties similar to those of fresh liquid whole eggs (Monfort et al., 2012). In addition, HPP can be used to improve the functions and emulsified quality of egg protein. Yan et al. (2010) reported the effects of high-pressure treatment at 100–500 MPa on particular physicochemical and functional properties of egg yolks. The results showed that high-pressure treatment induced a loss of solubility in the egg yolks and decreased the emulsifying activity index and free sulfhydryl content and surface hydrophobicity. Simultaneously, high-pressure treatment resulted in an increase in egg yolk viscosity. The differences in the modification of egg yolk protein using high-pressure treatment at various pressure levels may present differences in physical and chemical characteristics in commercial applications. In addition, investigating conformational and physiochemical changes under HPP is crucial because it can affect the functional properties and bioactivities of egg proteins. Ovotransferrin is a rich source of bioactive peptides, which account for 12–13% of egg white proteins. A study was recently conducted on the effect of high-

Table 1 Some current researches of high hydrostatic pressure in the area of fruits and vegetables

Product	Pressure conditions	Achievements	References
Avocado paste	600 MPa for 3 minutes	Storage up to 40 days at 4°C without any change in nutritional and nutraceutical values, particularly carotenoid profiles.	Jacobo-Velázquez and Hernández-Brenes (2012)
Dried strawberry	400 MPa for 10 minutes	Increased total phenolic content and retained vitamin C content.	Nuñez-Mancilla et al. (2012)
Aloe vera gel	400 MPa for 3 minutes	Microbial growth was completely suppressed during at least 90 days of storage at 4°C.	Reyes et al. (2012)
Orange juice	200 MPa for 30 seconds, at 20°C	Microbial quality and pectin methylesterase activity of pressure-treated juice was similar to thermally pasteurized.	Velázquez-Estrada et al. (2012)
Fruit smoothies	450 MPa for 5 minutes, at 20°C or 600 MPa for 10 minutes, at 20°C	The highest stability of the total antioxidant, phenols, and anthocyanin content was observed when the smoothies was pressured under 450 and 600 MPa and stored at 4 °C.	Keenan et al. (2012)
pomegranate juice	350–550 MPa for 30, 90 and 150 seconds	Good-quality juice with more than 35 days shelf life under refrigeration condition (4°C).	Vare-Santos et al. (2012)
Persimmon	200 MPa for 6 minutes, at 25°C	Increased extraction of carotenoid and retention of potential health-promoting tributes during cold storage	Plaza et al. (2012)

pressure treatment on the structure and physicochemical properties of ovotransferrin concentrate. The results showed that the conformational structure changed from helices, sheets, turns, and aggregated strands to mostly intermolecular β-sheets or aggregated strands at a pH level of 8 at 200 MPa; however, it returned to its original structure at higher pressures. These changes caused an increase in the surface hydrophobicity of protein, with no changes in the total SH groups; therefore, aggregation was inhibited (Acero-Lopez et al., 2012). The results of this study are promising in the development of a high-quality microbiology-safe product.

4.3. Dairy Products

The use of HPP for manufacturing dairy products has received considerable attention in recent years. HPP can preserve the flavor, texture, and nutrients of milk without any detrimental effects, extend the shelf-life, and present fresh-like products. Food safety risks and possible health benefits to consumers must also be considered. Compared the amount of free amino acids in HPP milk, original milk, pasteurized and sterilized milk, and milk processed using thermal processing techniques, and found that HPP milk has the highest amount of free amino acids, followed by pasteurized and sterilized milk and milk processed by using thermal processing. The results indicated that appropriate thermal processing may increase the amount of free amino acids; however, a part of free amino acids is destroyed as the temperature increase gradually. HPP milk retains all of the original ingredients, except for propylamine acid and cysteine, and retains a lower amount of aspartic acid. Another study indicated that original milk is sensitive to heat, and current thermal technology, such as pasteurization and high-temperature sterilization, deactivates the ingredients; therefore, these are inappropriate methods to process original milk. However, HPP enables the development and production of original milk, and can retain the active ingredients of heat-sensitive egg whites. The Fonterra Co-operative Group Ltd. uses HPP to produce original milk, and uses thermal sterilization on sugar and stabilizing agents, both of which are not sensitive to heat, before allowing them to cool and before adding the protein of the original milk. After acid moderation, homogenization, filling, canning, and finally, after undergoing HPP, this compound becomes a commodity in the market (Chawla et al., 2011). The potential of high-pressure homogenization as an alternative to heat pasteurization in inactivating food-borne pathogens has also been demonstrated in milk. High-pressure homogenization can induce microbial inactivation of milk by reducing total counts and lactococci, and by completely eradicating coliforms, lactobacilli, and enterococci. Previous studies on the cheese-making characteristics of high-pressure homogenization treated milk have focused on the rennet coagulation properties. High-pressure homogenization can enhance the coagulation properties of milk by decreasing the rennet coagulation time and increasing the curd firming rate and gel firmness (Zamora et al., 2012). The application of HPP to milk prior to cheese manufacturing has been scientifically explored, and combining of standard cheese manufacturing protocols with high-pressure treatment can produce high-quality cheese without the health risks caused by pathogen contamination, such as *Salmonella enteritis, L. monocytogenes*, or spore-forming bacteria. Undesirable bacteria are inactivated by applying pressure without the negative effect on cheese flavor that occurs after pasteurization (Martínez-Rodríguez et al., 2012). Voigt et al. (2012) observed that the high-pressure treatment of milk at 600 MPa prior to manufacturing cheddar cheese reduced initial microbial counts and increased proteolysis during ripening. Raw milk cheese is in high demand by consumers because of its unique traits; however, the cheese is prone to microbial contamination and flavor defects. The treatment milk with high pressure prior to cheese manufacturing facilitates the elimination of numerous risk factors, although it results in cheese with similar characteristics to that produced from untreated raw milk. This can help develop innovative and safe cheese, thus providing a competitive advantage. Bovine milk contains several bioactive components, such as lactoferrin, lactoperoxidase, and lysozyme, which are nonspecific factors that are effective against microorganisms. These properties are vulnerable to potentially denaturing conditions during heat processing. Pressure treatment of milk has considerable effects on milk proteins. High-pressure treatment induces disruption and reformation of casein micelles and the particle size of fat globules. For whey proteins, high-pressure applications produce changes in conformation, followed by aggregation mainly through sulfhydryl-disulfide interchange reactions (Sahu and Mallikarjunan, 2012). Mazri et al. (2012) studied the effect of high-pressure treatment on the denaturation of lactoferrin and lactoperoxidase present in skim milk and whey. The kinetic parameters obtained in this study facilitated the prediction of pressure-induced denaturation of lactoferrin and lactoperoxidase based on pressure and holding time; and the lactoferrin and lactoperoxidase denatured in milk slowly at 400 MPa. By contrast, denaturation in the whey was rapid at pressures above 700 MPa. The treatment performed at 600 MPa at 20°C reduced immunoreactive lactoferrin to approximately 75% and 65% in milk and whey, respectively, as compared with the corresponding untreated samples. High-pressure treatment also enhanced the denaturation of β-lactoglobulin and α-lactalbumin in skimmed milk and whey, and the phosphate buffer was examined within a pressure range of 450–700 MPa at 20°C. The degree of denaturation of β-lactoglobulin and α-lactalbumin was determined by measuring the loss of reactivity with their specific antibodies by using radial immunodiffusion, which expands the possibility of obtaining hypoallergenic hydrolysates of β-lactoglobulin and α-lactalbumin. Table 2 summarizes other key findings in this area of processing of dairy products.

4.4. Seafood

High pressurization of seafood products has been studied extensively in recent years, because seafood contributes a large proportion of food-borne diseases worldwide. The quality of seafood depends on the sensorial characteristics of the product, of which freshness is often reflected. Fish and shellfish predominantly cause food poisoning because traditional heat pasteurization has detrimental effects on taste and appearance; therefore, consuming raw or lightly cooked seafood may result in the transmission of diseases, such as *Vibrio, Salmonella, Clostridium, Listeria, and Escherichia coli*, as well as a number of toxins. In contrast to thermal processing, high-pressure treatment retains the appearance, flavor, and texture of seafood, and increases the safety and protects the product from possible pathogen contamination during minimal processing (Kaur et al., 2012). HPP provides long shelf life and minimal loss of quality because it does not cause several of the undesirable changes associated with thermal processing. HPP retains a fresh taste; however, structure, texture, and color can be negatively affected (Briones-Labarca et al., 2012; Aubourg et al., 2012; Montiel et al., 2012a, b). Kamalakanth et al., 2011 reported the effects of various high-pressure treatments on the K-value, total plate count, Enterobacteriaceae, and organoleptic characteristics of yellowfin tuna. The

Table 2 Some current researches of high hydrostatic pressure in the area of egg and dairy products

Product	Pressure conditions	Achievements	References
Liquid whole egg	300 MPa for 3 minutes	Combined application of HPP at 20°C (300 MPa/3 minutes) and heat (52°C/3.5 minutes or 55°C/2 minutes) to LWE with 2% triethyl citrate reduced more than 5 Log_{10} in *E. coli* and *L. innocua* with better physicochemical and functional properties than the ultrapasteurization heat treatment (71°C/1.5 minutes).	Monfort et al. (2012)
Goat milk cheeses	600 MPa for 7 minutes	Controlling microbial flora of cheeses without significantly influencing the cheese making properties.	Delgado et al. (2012)
Cheese	300 and 400 MPa for 5 minutes, at 6°C	Cheeses treated at 300 and 400 MPa, stored at 4°C, presented a shelf-life of 14 and 21 days, respectively, compared to untreated control cheese, which presented a shelf life of seven days.	Evert-Arriagada et al. (2012)
Cheddar cheese	600 MPa for 10 minutes, at 20°C	HPP treatment of milk at 600 MPa prior to manufacture of Cheddar cheese decreased initial microbial counts and increased proteolysis during ripening.	Voigt et al. (2012)
Cow milk	600, 500, 400, 300, and 200 MPa for 240, 200, 174, 144, and 110 seconds	The combination of high pressure with bacteriophage resulted in synergistic effect in controlling *Staphylococcus aureus* in pasteurized whole milk.	Tabla et al. (2012)

K-value of the samples decreased by increasing the pressure, as compared to the control. High-pressure treatments resulted in a decrease in the total plate count in the samples, which increased during storage. The Enterobacteriaceae decreased with increasing pressure and during storage. Erkan et al. (2011) indicated that high-pressure treated cold smoked salmon (250 MPa, 3°C for 5 five minutes and 250 MPa, 25°C for 10 minutes) was acceptable for up to 8 eight weeks of storage; therefore, the shelf life was extended by 2 eight weeks compared to the untreated samples. Ye et al. (2012) indicated that a hurdle technology of HPP followed by mild heat treatment can inactivate of foodborne illnesses of the *Vibrio* species in raw oysters. Combinations such as high pressure at 250 MPa for 2 two minutes followed by heat treatment at 45°C for 15 minutes and HPP at 200 MPa for 2 two minutes followed by heat treatment at 50°C for 5 five minutes reduced *V. parahaemolyticus* and *V. vulnificus* to non-detectable levels by using the MPN method. The product maintained the sensory characteristics of fresh oysters for an extended shelf life. Gou et al. (2010) found that HPP effectively retarded microbial growth, trimethylamine formation, and autolytic activity in sliced raw squids at 200–400 MPa. Moreover, recent advances in the use of high pressure to remove of meat from HPP treated shellfish enables the denaturing of the adductor muscle of oysters, caused the shell to open spontaneously, reduces the requirement for manual shucking, and increases the extraction yield of meat removed from high-pressure treated lobsters (Campus, 2010). Overall, the application of HPP as a method for improving the quality and acceptability of fish and shellfish-related products is beneficial to the seafood industry. Table 3 summarizes other key findings in this area of seafood processing.

4.5. Meat Products

Recent advances in the HPP of meat and meat products have created new methods for improving the microbial inactivation that results from high pressure and for minimizing the adverse effects of high pressure on meat quality, or use changes in meat attributes under high pressure. Among the food products that are processed by using high pressure, the number and variety of meat and meat products has increased substantially worldwide. Food products are mainly processed with high pressure to increase their safety by inactivating microorganisms without altering the attributes that contribute to sensory quality. Cured ham and particular precooked meals containing poultry, pork, chorizo, and various types of sausages are currently available in the European market (Simonin et al., 2012). Studies on NaCl-reduced foods have increased in recent years because of the relationship between high dietary sodium intake and increased cardiovascular diseases. Studies have shown that HPP is the result of a hurdles combination of several factors (i.e., biopreservation and HPP), that provide a wider margin of safety in the inactivation of pathogenic microorganisms during the storage of meat products. HPP has excellent potential as a complementary technology to reduce salt content and enhance product shelf life. Ferrini et al. (2012) indicated that NaCl reduction or the substitution of salt using KCl or K-lactate combined with a quick-dry-slice process and HPP allows the production of dry cured meat with reduced Na content, without effects on appearance and with lower microbiological risks. Fulladosa et al. (2012) indicated that using K-lactate combined with high-pressure (600 MPa) treatments provided an additional reduction in microbiological counts, increased the pinkness, brightness, hardness, and saltiness, and reduced pastiness and adhesiveness. Rodríguez-Calleja et al. (2012) applied a high-pressure-based hurdle strategy to extend the shelf life of fresh chicken breast fillets, and indicated that the high-pressure, modified atmosphere packaging, and antiseptic combination were particularly efficient in extending the durability of chicken breast fillets, and maintained their sensory and microbiological quality for up to 28 days. Simon-Sarkadi et al. (2012) reported that HPP treatment improved the

Table 3 Some current researches of high hydrostatic pressure in the area of seafood

Product	Pressure conditions	Achievements	References
Oyster	200–300 MPa for 2 minutes, at 21°C	HPP at 275 MPa for 2 minutes followed by heat treatment at 45°C for 20 minutes completely eliminated pathogens in oysters.	Ye et al. (2012)
Red abalone	500 MPa for 8 minutes and 550 MPa for 3 or 5 minutes	Sensory properties (microstructure, texture, and color) varied considerably after high-pressure treatment.	Briones-Labarca et al. (2012)
Abalone	200–550 MPa for 3, 5, and 10 minutes	Protein-starch interaction increases the emulsifying capacity at pressures over 350 MPa applied for 3–5 minutes.	Barrios-Peralta et al. (2012)
Black Tiger Shrimp	435 MPa for 5 minutes, at 25°C	Shelf life was extended to 15 days in shrimp treated at 435 MPa compared with 5 days in untreated sample.	Kaur et al. (2012)
Smoked cod	400 MPa for 10 minutes or 500 MPa for 5 minutes	Extended shelf-life and no differences in overall appearance and odor of smoked cod were reported after sensory evaluation.	Montiel et al. (2012)
Smoked salmon	450 MPa for 10 minutes	HPP combination with the lactoperoxidase added to smoked salmon can be used as a hurdle technology approach against *L. monocytogenes*, increasing the safety and the shelf-life during refrigerated storage.	Montiel et al. (2012)

microbial quality of sausages and was effective in reducing of biogenic amine formation during storage. Additionally, HPP has been used to improve the functional properties of muscle proteins because it can increase the solubility of a number of myofibrillar proteins and increase the binding between meat particles in patties following heat denaturation (Lee et al., 2011). HPP, procedures are performed on the surface of a product and permeate the entire packaging; therefore, the whole product is subjected to pressure, regardless of its size or form. This is especially advantageous to food products, such as sliced cooked meat, that are prone to pathogens, because they have a higher chance of contamination by pathogens. Some of the important finding in this area has been summarized in Table 4.

4.6. *Alcoholic Beverages*

Several studies have been conducted on the effects of HPP on liquid foods, such as fruit juices and milk; however, few studies have been investigated the use of HPP on alcoholic beverages. Traditional techniques for microbiologically stabilizing wines, such as filtration, pasteurization, and flash pasteurization at 60–70°C, negatively affect their sensorial quality and reduce their polyphenolic compounds, pigment, and volatile compound contents. However, HPP treatment can efficiently control Brettanomyces and avoid its negative effects (Morata et al., 2012). Bacterial wine spoilage is a concern in grape vinification. The negative impression of using chemical preservatives (SO_2) in wine present ongoing challenges in wine marketing. Although SO_2 acts as an antimicrobial agent and an antioxidant in wine, SO_2 can have negative effects on human health (Buzrul, 2012). Corrales et al. (2008) applied HPP to wine from the Dornfelder grape variety and monitored the stability of the predominant anthocyaninsm such as malvidin-3-O-glucoside (Mv3gl). A decrease in the concentration of Mv3gl in pressurized (600 MPa at 70°C for 1 one hour) samples was observed, whereas no loss of Mv3gl was observed in the heat-treated (0.1 MPa, 70°C for one hour) samples, compared to the untreated sample (0.1 MPa, 20°C for one hour). When the wine was subjected to 600 MPa at 70°C for 10 minutes, no substantial differences was observed in anthocyanin composition or antioxidant activity. Pasteurization based on high pressure has been successfully applied in numerous beverage industries to pasteurize products, and recent trials using grape and wine have yielded positive results. Health concerns and changing regulatory requirements provide further motivation for the winemaking community to use alternative methods in limiting the proliferation of wine spoilage bacteria, and these emerging technologies may provide support in this objective (Bartowsky, 2009).

Beer is the most consumed alcoholic beverage worldwide, and the brewing industry has an ancient tradition and is a dynamic sector that is open to modern technology and scientific progress. Breweries have directed their efforts to produce beers with the highest possible organoleptic stability to meet consumer requirements for beer that retains its taste during its shelf life. Buzrul et al. (2005) investigated the effects of HPP on the shelf life of lager beer. Filtered bright lager beer samples were treated using HPP (350 MPa for three and five minutes at 20°C) or conventional heat pasteurization (60°C

Table 4 Some current researches of high hydrostatic pressure in the area of meat products

Product	Pressure conditions	Achievements	References
smoked dry-cured ham	600 MPa	HP treatment at 600 MPa on hams at 50% weight loss reduced microbiological counts, increased pink color, brightness, hardness, and saltiness and reduced pastiness and adhesiveness.	Fulladosa et al. (2012)
Chicken breast fillets	300 MPa for 5 minutes, at 20°C	Color, tenderness, and overall acceptability were the best maintained sensory attributes during storage for HPP and modified atmosphere packaging.	Rodríguez-Calleja et al. (2012)
Pork	600 MPa for 6 minutes	HPP treatment induced an increase in cathepsin activity, which subsequently affected the myofibrillar protein degradation pattern in pork meat.	Grossi et al. (2012)
Beef	172–620 MPa for 1–5 minutes, at 25°C.	The color, texture, and tenderness of treated and untreated meats were not statistically different ($p > 0.05$). High hydrostatic pressure preserved meat over a longer time period and is a promising technology for extending the shelf life of raw meat.	Sánchez-Basurto et al. (2012)
Sausage	500 MPa for 10 minutes	HPP treatment improved the microbial quality of the sausages and it was effective in the reduction of Biogenic amines formation during storage at 8°C for one month.	Simon-Sarkadi et al. (2012)
Cured meat	500 and 600 MPa for 7 minutes	The NaCl reduction or the substitution of salt by KCl or K-lactate combined with Quick-Dry-Slice process and HPP allows the production of dry cured meat with reduced Na content, without important effects on appearance and with lower microbiological risks.	Ferrini et al. (2012)

for 15 minutes). A storage period of 56 d showed that HPP and heat pasteurization yielded similar results in pH and color. However, the HPP-treated samples had lower bitterness and protein sensitivity and higher chill haze values than did the heat-pasteurized samples at the end of the storage period. The microbiological stability of the HPP-treated beers was the same as that of heat-treated beers, and the development of both lactic and acetic acid bacteria was inhibited for 56 days of storage. Buzrul et al. (2005) also studied the effect of HPP on the quality parameters of larger beer. Unpasteurized lager beer samples from a commercial brewery were treated using HPP (200, 250, 300, and 350 MPa for 3 three and 5 five minutes at 20°C) or conventional heat pasteurization (60°C for 15 minutes). The main attributes of the beer, such as ethanol content, density, extract, fermentation degree, and pH, were unaffected by both treatments; however, HPP and heat pasteurization affected the color, chill haze, protein sensitivity, and bitterness. The color, protein sensitivity, and chill haze values increased in conjunction with the pressure and pressurization time. The change in bitterness was higher in conventional heat pasteurization; however, pressures of up to 300 MPa did not substantially affect the bitterness. Buzrul et al. (2012) indicted that HPP treatment inactivates undesirable microorganisms and improves the organoleptic properties of beer. The pressure levels used to treat the beer were similar to those in commercial applications in the fruit juice industry; that is, 400–600 MPa. The HPP-treated product has a fresh-like taste that attracts the attention of consumers. Therefore, HPP can eliminate the negative effects of heat on the aroma and flavor of beer and reduce SO_2. Although few studies have investigated the use of HPP in producing alcoholic beverages, this technology can be used in the wine industry to improve the quality of products and provide an alternative environmentally friendly technology.

4.7. *Food Biotechnologies*

Most natural food products, such as fruits and vegetables, are rich sources of a wide range of essential micronutrients and biologically active phytochemicals. Hence, certain fresh plant foods may be amenable to the HPP process, and applying this novel technology to foods rich in these bioactive agents may be useful for developing healthier food products for consumers. HPP has considerable potential for various industrial fields, including the food and pharmaceutical industries, and can be used to decontaminate various products or biomaterials and produce new types of healthy foods and medicines. Al-Habsi and Niranjan (2012) indicated that the antimicrobial effect of Manuka honey can be enhanced by using HPP without adversely affecting the quality of the honey. Vega-Gálvez et al. (2012) indicated that HPP is an innovative technology that can be used to improve the shelf life of aloe vera gel, which enhances its antioxidant activities. Hu et al. (2012) indicated that HPP effectively induces the formation of the β-CD-Vc inclusion complex, which is a nutrimental biomaterial. The incidence of food allergies has increased in recent years, leading to a demand for methods that reduce allergens in food products. HPP can reduce the allergenic activity of foods such as eggs, milk, peanuts, soybeans, and apples (Kim et al., 2012a, b; López-Expósito et al., 2012; Tong et al., 2012; Mazri et al., 2012; Li et al., 2012; Cabanillas et al., 2012), thereby leading to a reduction in allergenicity by irreversibly removing of allergens or modifying the allergen structure to prevent the immune system from recognizing the allergenic epitopes. This can alter the allergenic properties of food products and enhance the safety of allergenic food.

5. *PROSPECTS OF HPP APPLICATION AND ADDITIONAL TOPICS*

HPP has been widely studied over the past many years. Commodities such as juice and jam processed using HPP are currently marketed in Japan, European countries and the United States. HPP can eradicate microorganisms at mid-to-low temperatures and deactivate enzymes without negatively affecting on the organoleptic qualities or nutrition values. HPP combined with electron fields, ultrasounds, irradiation, carbon dioxide, and antimicrobial peptides can reduce the pressure of operations and costs. Although HPP may not replace traditional methods of food processing, it can be considered a supplementary approach to facilitate the development of a commodity. The future application of HPP is promising with the further development of HPP technology, the formulation and stipulation of food-related laws and regulations, and the enhancement of manufacturing capability and facilities. HPP, which is based on the principles of Pascal and Le Chatelier, operates in a moisture-pressing manner because water is the main component of all foods. Pascal's principle states that moisture can be instantaneously and evenly distributed across the entire system by pressing liquids with high pressure. However, installing HPP requires metal materials and a heavy structure that can resist high pressure; thus, it occupies considerable space and incurs high costs. In addition, repetitively adding and decreasing pressure may damage the air-tight high-pressure body and pressure-adding container. Thus, the currently used high-pressure installation involves using approximately 300–600 MPa of pressure. Moreover, the activation of enzymes in foods may differ because of varying structures and amounts, and adding pressure is expected to deactivate make all enzymes. If the product contains residue of enzymes, it is stored in a low-temperature condition to maintain quality. Although data on HPP food are currently available, the actual conditions must be set for every food product. Regarding spores in low-acid foods, the traditional thermal techniques involve using 180°C for 5–15 minutes in a dry environment, 180°C for five hours in a wet environment, and 121°C for 30 minutes under a high-pressure steam condition. If used with HPP, a temperature of over 70°C and a pressure of 600–1000 MPa are required for sterilization. Moreover, food shrinks under high pressure, and can only be packaged with soft packaging. HPP foods are not a larger part of the international market. The reasons are explained in the following subsections.

5.1. Flavor of the Food Requires Improvement

Because of the slight increase of the temperature of the system, HPP only affects only the non-covalent bonds of the 3D structure of high molecular substances; therefore, browning (such as the Maillard reaction) dose not occur. Consequently, the color and aroma produced from browning cannot be produced. This is both an advantage and a disadvantage of HPP; in other words, no specific aroma, such as that of thermal treatment, is produced. However, this problem may be resolved using a double treatment, that is, pressure combined with a thermal approach.

5.2. Stricter Requirements for Sterilization

Because various microorganisms and enzymes have differing resistances to pressure, the pressure conditions to eradicate various microorganisms and deactivate enzymes vary. Therefore, inappropriate pressure conditions may result in the retention of microorganisms and enzymes, which may lead to rotting and changes in quality. Hence, when using traditional thermal treatment, requirements vary for the transportation and storage of food that can be transported at normal temperatures. Foods processed with high pressure can be affected from the aspects of flavor, color, and gels, which may go limp because of the remaining oxygen inside the container or that which has permeated the plastic material. Therefore, food must be conveyed at low temperatures to ensure its freshness, and refrigeration or freezing facilities are required in warehouses and hyper marts, thus increasing production costs.

5.3. High Requirements of Materials

Most raw materials are obtained from agricultural products, in which pesticides may remain. Thermal treatment may reduce the amount of pesticides through heat breakdown or evaporation, however, HPP dose not have such an opportunity to reduce the remaining pesticides during processing. HPP can only eliminate toxins and dangerous materials in the pretreatment phase or use non-contaminated raw materials.

5.4. Limited Choices of Food Product Containers

HPP involves procedures such as the packaging of raw materials and high-pressure treatment; therefore, food containers must be equipped with deformability, restorability, heat integration, and low oxygen permeation. Currently, the only material that meets these requirements is plastic; therefore, the use of several traditional packaging materials is limited.

5.5. High-cost Equipment

HPP requires high-pressure equipment, which is expensive and difficult to manufacture because durability, resistance to pressure, and the wall thickness of the container must be considered. In the initial phase, the investment capital can be high, the operation is intermittent, the workload is small, and the production effectiveness is lower than that of thermal sterilization, thus increasing the cost of production.

6. CONCLUSION

The application of emerging non-thermal technology has potential for high-quality and safe food products. The application of HPP can inactivate pathogenic microorganisms and enzymes and modify structures with little or no effect on the nutritional and sensory quality of foods. HPP is a technology that can achieve the food safety of heat pasteurization and meet consumer requirements for fresher-tasting minimally processed foods. Although UHP processing technologies have limitations related to high investment costs, full control of variables associated with the process operation and lack of regulatory approval have delayed a wider implementation of these technologies on an industrial scale. However, high-pressure-treated food can meet future requirements for simple, safe, natural, and nutritious food. Therefore, HPP technology has enormous market potential.

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