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Agriculture and Agricultural Science Procedia 10 (2016) 377 – 383

Agriculture and Agricultural Science
Procedia

5th International Conference "Agriculture for Life, Life for Agriculture"

High Pressure Processing in Food Industry – Characteristics and Applications

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Abstract

The paper aimed to present high pressure processing of food used to process liquid and solid foods with a high content of moisture. When using high pressure processing, microorganisms are destroyed, but covalent bonds do not break and the effect on processed food is minimal. In addition, the positive effect consists of the avoidance of excessive thermal treatments and chemical preservatives. High pressure has a small effect on low-molecular-weight compounds such as flavor compounds, vitamins, and pigments compared to thermal processes. Therefore, the quality of high pressure pasteurized food is very similar to that of fresh food products. The quality of foodstuffs during their shelf life is influenced to a greater extent by subsequent distribution and storage temperatures or by packaging rather than by the pressure treatment itself. Food products can be HPP in a batch system or a semi-continuous process. During HPP, the pressure is applied uniformly and simultaneously in all directions. After HPP the food will not return to its original size and shape due to pressure differences between the compressibility of air and water, unless the food is perfectly elastic. Pressure is instantaneously and uniformly transmitted independent of the size and geometry of food. Resultant pressure regulates most subsequent biochemical reactions occurring in treated products. This article provides an overview of current technology status.

Peer-review under responsibility of the University of Agronomic Sciences and Veterinary Medicine Bucharest

Keywords: High pressure; food quality; food processing; non-thermal preservation; high pressure processing

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Peer-review under responsibility of the University of Agronomic Sciences and Veterinary Medicine Bucharest
doi:10.1016/j.aaspro.2016.09.077

1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

Nomenclature

HPP	High-pressure processing
PE	polyethylene
PP	polypropylene
UHP	Ultra-high-pressure processing

High-pressure processing (HPP) is a non thermal technique of food preservation that inactivates harmful pathogens and vegetative spoilage microorganisms by using pressure rather than heat to induce a pasteurization effect. HPP employs intense pressure (about 400 – 600 MPa) at refrigeration or mild process temperatures (< 45°C), preserving most foods with minimal effects on taste, texture, appearance, or nutritional value. Pressure treatment can be used to process both liquids and solid foods with a high content of moisture. Although lethal to microorganisms, pressure treatment does not break covalent bonds and has a minimal effect on food chemistry. On the other side, HPP provides a means to retain food quality while avoiding the need for excessive thermal treatments or chemical preservatives. High-pressure processing is also referred in current literature as high-hydrostatic pressure processing (HHP) or ultra-high-pressure processing (UHP).

Some of the advantages of applying HHP are (Penchalaraju, 2013):

- inactivation of vegetative bacteria and spores at higher temperatures;
- no evident of toxicity;
- preservation of nutrients, colors and flavors;
- reduced processing times;
- uniformity of treatment throughout food;
- potential for reduction or elimination of chemical preservatives;
- positive consumer appeal.

Some limiting aspects of HHP are:

- expensive equipment;
- foods should have 40% free water for anti-microbial effect;
- batch processing;
- limited packaging options;
- little effect on food enzyme activity;
- some microbial survival.

Some commercial applications for food products could be:

- pasteurization of meats and vegetables;
- pasteurization and sterilization of fruits, sauces, yoghurts and salad dressings;
- decontamination of high risk and high value heat sensitive ingredients including flavorings and vitamins.

2. High Pressure Processing (HPP) Principles

The use of commercial high-pressure processing of foods is increasing. It provides processors an opportunity to preserve foods, being the process of choice for applications where heat pasteurization would adversely affect product quality. Le Chatelier's principle states that any phenomenon (phase transition, change in molecular configuration, chemical reaction) leading to a decrease in volume is enhanced by pressure. Therefore, after HPP the food will not return to its original size and shape due to pressure differences between the compressibility of air and water, unless the food is perfectly elastic.

The principles of microbial inactivation of HPP have been known since the late 1800s (Hite, 1899), but it began to be used on a large scale only in the last 20 years, when recent innovations allowed the construction of high pressure vessels with sufficient durability to withstand thousands of pressure cycles without damage, at a prices.

The basic components of a HPP system are a pressure vessel, a pressure-transmitting fluid, a material handling pressurizing system, and supporting units such as heating or cooling components etc. as shown in figure 1 (Heremans, 2003).

The most common transmitting fluids are water, food-grade glycol–water solutions, silicone oil, sodium benzoate solutions, ethanol solutions, and castor oil (Balasubramaniam et al., 2008).

Food products can be HPP in a batch system or a semi-continuous process.

During HPP, the pressure is applied uniformly and simultaneously in all directions. It is called isostatic pressure and it is the reason why food is not crushed during the treatment. This is the major advantage compared to thermal methods where the temperature of product is increased gradually (Balasubramaniam et al., 2008). Once loaded and closed, the vessel is filled with a pressure-transmitting medium. Air is removed from the vessel with an automatic deaeration valve by means of a low-pressure fast-fill-and-drain pump, and high hydrostatic pressure is then generated by direct or indirect compression or by heating the pressure medium (Mertens, 1995).

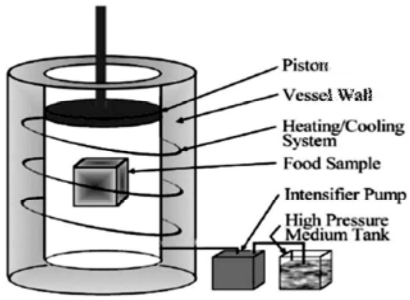

Fig. 1. Basic components of HPP.
(Source: Naik, 2013)

According to these principles; the phenomenon of phase transition and chemical changes are accompanied by a decrease in volume; favored by pressure and vice-versa. Pressure is instantaneously and uniformly transmitted independent of the size and geometry of food. Resultant pressure regulates most subsequent biochemical reactions occurring in treated products.

In biological systems, the changes brought about by the volume-decrease reactions of HPP include denaturation of proteins, gelation, hydrophobic reactions, phase changes in lipids (and, therefore, in cell membranes) and increases in the ionization of dissociable molecules due to „electrostriction" (Heremans, 2003). The high pressure process is characterized by three parameters: temperature (T), pressure (p) and exposure time (t) when compared heat preservation.

Typical pressures applied to foods range from 300 – 800 MPa (table 1).

Table 1. Aspects of salient findings and potential application in dairy industry.

Conditions	Product and Salient results	References
200-250 MPa	The combination of high pressure with bacteriocin such as lacticin resulted in synergistic effect in controlling microbial flora of milk without significantly influencing the cheese making properties	Morgan et al., (2000)
100-600 MPa/ 0-30 min at 20°C	Rennet coagulation time of heated milk decreased with increasing pressure and treatment time. The strength of the pressure treated coagulum from heated milk was considerably greater and the yield of cheese curd also found 15% greater than that from unheated /unpressurized milk; the protein content of the whey was 30% lower	Huppertz et al.,(2002)
200-400 MPa	Pressure treatment of cheese milk increased the yield of lowfat cheese by improving protein and moisture retention. Pressurization of pasteurized milk improved its coagulation properties. Cheese made from pressurized and pasteurized milk showed increased protein and moisture retention as well as improved coagulation properties. The protein degradation and development of texture and flavor was also rapid and the product had lower hardness and cohesiveness and higher sensory scores	Molina et al., (2000)
200-500 MPa/ 60 min, 20◦C	Periodic oscillation of pressure was very effective for the destruction of pathogen such as Listeria monocytogenes, Escherichia coli and Salmonella enteritidis.	Vachon et al., (2002)
300-600 MPa	Increase in cheese yield by high-pressure treatment of cheese milk due to denaturation of whey proteins and increased moisture retention was also found. Higher moisture content of cheese made from high-pressure treated milk due to the fact that casein molecules and fat globules may not aggregate closely and may allow moisture to be trapped or held in cheese.	Drake et al., (1997)

(Source: Naik, 2013)

3. The Effect of HPP on the Chemical Composition of Food

It is important to note that some temperature increases do naturally occur during a typical HPP treatment due to adiabatic heating. They depended on the target pressure and the chemical composition of food.

The temperature increase of water is approximately 3°C per 100 MPa, but it can be significantly higher for more compressible food ingredients such as fats. Thus, the temperature increase is higher during HPP for foods with a higher fat content.

A representation of the pressure and temperature profile of a typical HPP treatment is shown in figure 2 (Ferstl, 2013).

The effect of HPP on molecules with a low molecular weight is minimal. Therefore, vitamins, flavor compounds, and pigments survive HPP processing relatively undamaged compared to thermal processing. In this way the nutritional value and quality of the food is preserved.

On the other hand, some compounds are irreversibly changed during HPP. Gelatinization of carbohydrates can be achieved through pressure increases rather than through temperature increases, and proteins can be denatured at high increasing the temperature.

Figure 3 illustrates this pressure-temperature relationship.

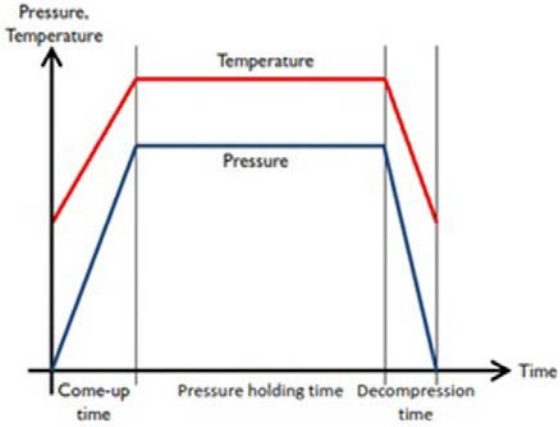

Fig. 2. Pressure, temperature and time during a HPP process.
(Source: Ferstl, 2013)

The egg shown in figure 3 is visually similar to a thermally-processed hardboiled egg. The taste of the pressure-treated egg is, however, closer to that of raw egg, as temperature-induced flavor changes (chemical reactions) did not occur during HPP. This opens new product development possibilities.

To achieve the best pressure transmission, the ideal food for HPP has no gas inclusions, no empty spaces in the package, and a high content of moisture. Additionally, the packaging material has to be appropriate: it has to be flexible enough to transmit the pressure with no structural damage. The food is compressed during pressurization, and the package has to permit a reversible deformation.

The most common packaging materials used for HPP of food are polypropylene (PP), polyester tubes, polyethylene (PE) pouches, and nylon cast polypropylene pouches. Plastic packaging materials are best suited for HPP because of their reversible response to compression, their flexibility and resiliency.

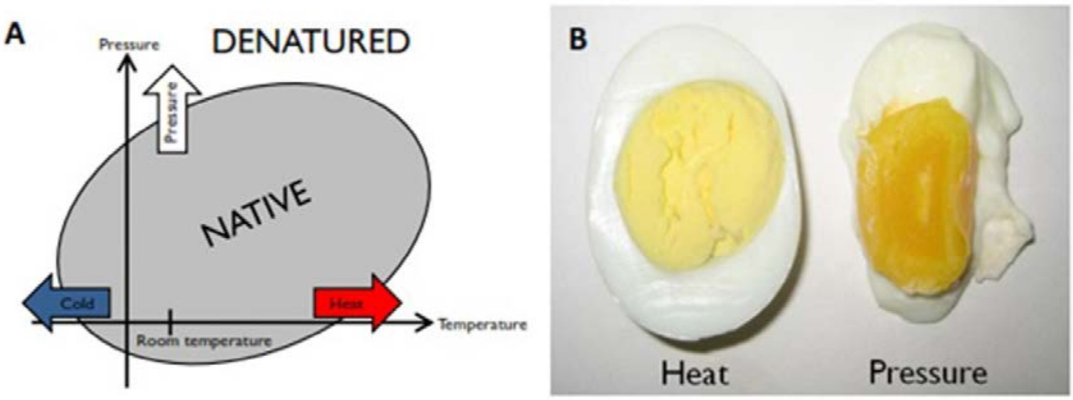

Fig. 3. A. Schematic representation of the elliptic phase diagram of proteins illustrating pressure, heat and cold denaturation
(A) and B. picture of denatured eggs.
(Source: Smeller, 2002)

This is especially true for vegetative microorganisms including yeasts, lactic bacteria, spoilage organisms and pathogens such as: *Escherichia coli*, *Salmonella* and *Listeria monocytogenes.*

Many studies performed on a variety of food products inoculated with these organisms have demonstrated the efficacy of HPP to inactivate all food-borne microorganisms.

From a microbial perspective the major benefits of HPP of food products are extended shelf life and improved food safety.

Rigid materials such as metal and glass are not recommended, as they will not be able to undergo HPP treatment.

Vacuum packed products in flexible packages appear ideal for HPP, particularly if the packaging could be compressed by about 15% with no structural damage and if it were able to return to its original shape upon pressure release. Currently, flexible packs, jars, trays and bottles are used as HPP packaging.

4. The Effect of HPP on Microorganisms

The high pressure affects the microorganisms in a similar manner to that described for chemical components of food. Denaturation of proteins, which are essential to many of the functions of the bacterial cell, has a major impact on the survival of microorganisms. This can eventually lethally damage the cell if a sufficient amount of pressure is applied. The recovery of bacterial cell is, thus, made impossible.

On the other hand, HPP is not effective against all microbial forms. Spore-forming microorganisms are highly resistant to HPP when in spore form. Thus, a combination of pressure and heat, or other antibacterial treatment is required to achieve a significant reduction of bacterial spores in foods.

Compared to vegetative cells, endospores tend to be extremely resistant to high pressure processing. They require a combination of high pressure treatment at pressure exceeding 1000 MPa and heat treatment with temperatures above 80°C (Smelt, 1998, Abee and Wouters, 1999).

Yeasts and molds are relatively sensitive to HPP. Most vegetative species are inactivated within a few minutes by 300 - 400 MPa at room temperature. However, yeast and mold ascospores may require treatment at higher pressures. Viruses show a wide range of sensitivity in response to high pressure.

Clostridium botulinum spores are of particular concern because they can germinate, grow, and produce the highly potent paralytic neurological toxin in low acid foods.

Two of the factors influencing the effectiveness of the HPP treatment against microorganisms are: the chemical composition of the food products and the type of microorganisms (Alpas et al., 1999; Benito et al.,1999). Some may be able to grow or survive in the product, becoming the dominant microflora, thus a careful evaluation of HPP should be made when applying the treatment on a specific food product.

Regulatory agencies have specified “critical processing parameters” for HPP treatment of foods. They include: target pressure, the interval of time to achieve target pressure, decompression time, initial temperature of the product, initial temperature of the pressurization fluid, pH of the product, the water activity of the product.

Currently, several HPP products are commercially available such as: vegetable and fruits – juices, salsas, dressings, meats; ready-to-eat meats and poultry, seafood, shellfish and fish products.

5. Conclusion

Further research is needed to characterize the combined pressure-thermal resistance of pathogenic and spoilage microorganisms as a function of the food matrix, pH, and water activity. Standardized reporting of process conditions, equipment, and microbial techniques utilized are needed to develop a comprehensive database of inactivation kinetics. Additionally, molecular path-way studies are essential to improve current understanding of the effects of combined pressure-thermal treatments on microorganisms. The extent and mechanisms of bacterial injury during high- pressure pasteurization and sterilization need further investigation.

The increase of temperature in food stuffs under pressure is dependent on factors such as final pressure, product composition, and initial temperature. The temperature of water increases by about 3°C for every 100 MPa of pressure at room temperature (25°C). On the other hand, fats and oils have a compression heat of 8–9°C/100 MPa, while proteins and carbohydrates have intermediate values.

Pressure-transmitting fluids delivers pressure uniformly and instantaneously to the sample.

The effect of high pressure processing on microorganisms has been widely investigated. Microorganisms vary in their response to high pressure and there can be varying high pressure sensitivity among bacterial species and even strains

Packaging materials for high pressure processing must be flexible to withstand a 15% increase in volume followed by a return to the original size, without losing physical integrity, sealing or barrier properties. The empty space in the package must be minimized to control the deformation of packaging materials and ensure efficient use of the space in the pressure vessel. An efficient HPP treatment should not affect the mechanical properties, the delamination and the sealing integrity of the packaging nor its barrier properties (permeation - oxygen, water, carbon dioxide, sorption - aroma loss and migration -additives, odors). These are crucial requirement for the quality and safety of the food.

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