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REVIEW ARTICLE

THE APPLICATION OF HIGH HYDROSTATIC PRESSURE IN MEAT AND MEAT PRODUCTS: A REVIEW

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ABSTRACT

Heat treatment processes are widely used because they inactivate microorganisms and enzymes. However, thermal applications lead to changes in the physical and chemical structure of foods, as well as to deterioration of their sensory properties and natural components. For this reason, studies have been conducted on non-thermal technologies for food preservation. This technology extends the shelf life of foods and provides microbiologically safe, higher quality products. From the studies, it has good potential for the meat industry. The aim of this review was to compile the current state of research in this field and provide information on the characteristics, applications, advantages and disadvantages of non-thermal high hydrostatic pressure technology in meat and meat products.

Keywords: *High hydrostatic pressure, Meat quality, Meat products, Sensory, Texture profile*

1. INTRODUCTION

Numerous thermal and non-thermal processes have been developed in the meat industry to meet consumer demand for less processed products. Among all these non-thermal processes, the use of high hydrostatic pressure (HHP) is perhaps the most widely used [1]. High hydrostatic pressure is now used in the meat industry in many countries [2]. As a result, both food scientists and industry are increasingly interested in HHP processing [3]. Since this technology is applied at normal temperatures, which is one of the outstanding methods within the alternative processes, is one of the preservation methods that minimizes the negative effects that can be caused by high temperatures [4].

High hydrostatic pressure process is widely used not only for meat and meat products, but also for seafood, fruits and vegetables [5]. HHP is a physical process in which food is subjected to uniform pressure treatment from all directions [6]. It is a process in which solid and liquid foods are subjected to pressures of 100-1000 MPa with or without packaging [7; 8; 9; 10; 11; 12; 13]. Commercially, pressure application times range from milliseconds (by agitator pumps) to over 1200 seconds [14]. Sterilization of packaged foods by high hydrostatic pressure allows lower energy consumption and reduction of chemical additives and preservatives [15]. The main principle is the compression of water by the surrounding material [7; 9; 11, 16]. However, it is also extremely important that the product is placed in a flexible container before the food is subjected to this process [17]. The packaging material should be able to form a strong barrier (about 15% deformation at 600 MPa for vacuum packed meat) and not migrate into the product [18].

The effects of HHP application on microorganisms and proteins/enzymes are similar to the effects of high temperatures. HHP is considered as "light technology" [19]. Thanks to low temperature, the natural properties of food such as smell, taste texture, and nutritional values are better preserved [20]. High pressure affects the morphological structures of microorganisms. The cell structure is very sensitive to pressure [21]. A pressure of several tens of MPa can reduce the growth rate, while a pressure of several hundreds of MPa can reduce the viability of bacterial cells [22]. Increasing the pressure and time applied to the food accelerates microbial inactivation [23].

High hydrostatic pressure does not break the covalent bonds [4]. During the preservation process, vitamins, flavors, and color molecules are preserved without degrading [24]. High hydrostatic pressure has the most application in meat technology [25]. In addition, HHP of meat products is a fast-growing industry as shown by the large number of patents granted in recent years [26]. This application has been developed and put into practice in many countries to obtain soft meat and improve its quality [27]. Food treated with high hydrostatic pressure is now commercially produced in developed countries [28].

A high hydrostatic pressure system consists of four main parts [29]:
- Pressure vessel
- Pressure generation system
- Material conveying system
- Temperature control device

The pressure chamber is loaded, closed, and degassed, and the pressure is transferred to the food via a liquid using a pump. HHP accelerates reactions involving volume change at the molecular level [18]. Special hydraulic oils, hydrocarbons, or water are used as pressurized fluids to transfer the pressure applied in the high-pressure hydrostatic system to the food. However, in practice, water is most commonly used because it reduces volume and is cheaper than gasses [30].
The main applications of high hydrostatic pressure are shown in Figure 1 [8, 16].

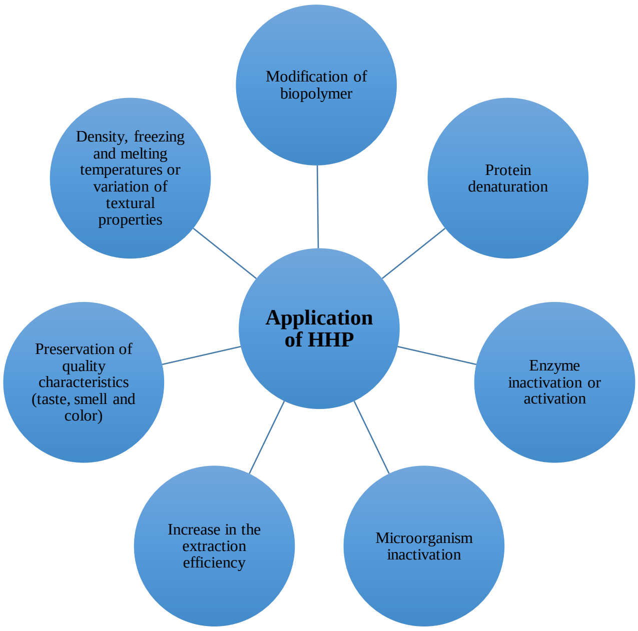

Figure 1. The main applications of HHP.

The advantages of using HHP

- Environmentally friendly method, as it consumes only electrical energy and does not generate waste [19].
- Since the pressure is evenly distributed on the food, it ensures homogeneous preservation of the food [8]
- Short processing times (compared to traditional methods) [11]
- The pressure to be applied does not depend on the shape and size of the food. Therefore, separate process parameters for each food are not required [31]
- HHP can be used to reduce the salt amount of emulsion-type meat products [8].

The disadvantages of using HHP [31]

- HHP requires the use of specially designed packaging.
- Some enzymes are resistant to high pressure processing, which affects food quality.
- High investment cost.

2. HISTORY of HHP

The first application of HHP in the food industry was carried out by Hite in 1899 for pasteurization of milk and fruit products [26]. It was found that the shelf life of milk could be extended by 4 days by

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subjecting raw milk to 600 MPa pressure at room temperature for one hour. Between 1970 and 1980, there were positive developments in the ceramic and metal industries. In the 1990s, various commercial food products entered the Japanese market. Japan is now a world leader in jam, marmalade, juice, yogurt, salad dressing, and fruit sauces [7, 8].

3. EFFECTS ofF HHP on MEAT QUALITY

HHP increases meat crispness, microbiological inactivation, pasteurization, prevention of overcooking, extension of storage time in the refrigerator, binding and gelatinization of sausage and salami meat with the help of pressure. It has been found to have many beneficial effects, such as increasing the capabilities of the meat, less dissolution losses at low temperatures, and faster dissolution of the meat [32].

This technology is a practical method for inactivating microorganisms in prepared foods, the shelf life of which is highly dependent on good hygiene and manufacturing practices. Therefore, many studies are concerned with the use of high hydrostatic pressure applications to extend the shelf life of raw hams, specialty sausages, etc. [26].

Additionally, to the microbiological quality of meat and meat products, physicochemical properties are also important for consumer preferences. The color of meat products, which is one of the most important quality characteristics, is an important criterion for consumer selection and purchase of the product [33]. It can also be used for the tenderness of meat [34]. HHP treatment of fresh meat products can result in a cooked appearance. Sometimes this application cause rubbery texture [35]. In addition, it has very important effects on lipid oxidation, color, and phase change of meat. It has also been reported that the salt content of emulsion meat products can be decreased [34].

In addition, the using of HHP reduces the heat required for the dissolution process and does not effect the appearance, shape, and size of the products because the pressure is uniform in the samples. Due to these advantages, freezing and thawing methods have been the focus of interest for many researchers in recent years [36]. The studies on HHP technology for meat and meat products are listed in Table 1.

Table 1. Studies of HHP technology in meat and meat products.

PRODUCT	PROCESS CONDITIONS	BASIC EFFECT	REFERANCE
Biceps femoris veal patties	High Hydrostatic Pressure (350, 475, or 600 MPa) for 5, 10, or 15 minutes) and sous vide cooking technique (55, 60, 65°C) combination	• Significant changes in color and texture parameters were reported in the HHP and sous vide combination. • Combinations of 350 MPa for 10 minutes and sous-vide cooking at 55°C reduced hardness and cooking loss.	[37]
Iberian	600 MPa for 8	• Microbial counts decreased.	[38]

"*salchichón*"	minutes	• *L** and *a** values decreased during storage at 20 °C. • *b** values increased. • Color changes were reported in the sensory evaluation. • Lipid and protein oxidation values increased.	
Yellowfin Tuna Meat -individual histamine-forming bacteria inoculated (*Morganella morganii* & *Photobacterium phosphoreum*)	250, 350, 450 and 550 MPa, 5 minutes	• The number of Histamine-forming bacteria decreased significantly as the high hydrostatic pressure increased. • Histamine-forming bacteria were not found in samples treated at 450 and 550 MPa.	[39]
Raw and smoked trout	200 MPa, 15 minutes, liquid smoke (0.50%, v/v) and freezing (−80 °C, overnight)	• HHP, liquid smoke, and freezing were found to have a significant synergistic effect, resulting in a 5.48 or 1.93 log CFU/g reduction when smoked or raw trout were used, respectively.	[40]
Red Claw Crayfish *Cherax quadricarinatus*	200 MPa, 400 MPa, and 600 MPa	• A statistically significant decrease in the moisture value. • Except for the crude lipid content, no statistically significant differences in ash, crude protein, or crude lipid content were found between the 200 MPa and 600 MPa treatments.	[41]
New Zealand lamb meat	200–600 MPa	• The total free amino acid composition increased significantly at all applied HHP when compared to the control. • It has been reported that 400 and 600 MPa pressure application resulted in higher levels of TBARS.	[42]
Fresh beef	300, 600 MPa	• The combination of treatments provided acceptable color and microbiological stability during 4 and 6 weeks of storage at 4^{o}C.	[43]
Chicken breast	600 MPa, 2 minutes, 20 °C	• HHP treatment of cooked chicken resulted in a <3.3 log reduction	[44]

		of *Listeria monocytogenes*. • A combination of 2% Na lactate and high pressure maintained *Listeria monocytogenes* numbers below 50 CFU/g during storage.	
Inegol meatballs	100-200-400-600 MPa, 10 minutes, 4℃.	• Pressure application increased the gel strength and improved its elastic properties. • The microbial load decreased with the increase in the pressure level. • High pressure had negative effects on the color parameters of uncooked meatball samples. However, it was reported that after firing, the color difference disappeared. • The panelists stated that the consistency, flexibility and flavor of the patties, which were pressurized especially at 200-400 MPa, were better.	[45]
Sausages (mechanically separated poultry and minced pork)	500 MPa, 50-60-70-75 °C, 30 minutes or cooked at 75 °C, 30 minutes	• More flexible and firm but with a more cohesive sausage structure. • High pressure can impart an acceptable texture to cooked sausages produced with mechanically separated poultry meat.	[46]
Tilapia fillets	220MPa, 10 minutes	• *L** values of the HHP and UV+HHP applied groups were found to be higher than the control and only UV-treated samples.	[47]
Tan Mutton	100, 200, 300, 400 MPa 15 minutes 25 ± 1°C	• The tenderness value of lamb leg meat increased when 200 MPa pressure was applied.	[48]
Beef mince meat (frozen, unfrozen, vacuum-packed)	350 MPa, 10 minutes, 10 ◦C	• Freezing and high hydrostatic pressure caused increase pH value and decrease TBA value.	[49]
Rendered pork fat	800MPa, 19°C, 20 minutes	• The pressure treated samples have a higher peroxide value compared to the control group samples. This effect became more pronounced as the pressure increased. • The extent of lipid oxidation at	[50]

		800 MPa for 20 minutes was increased by increasing the treatment temperature.	
Beef	100- 600 MPa, 260 seconds at 10 °C	• While the myofibrils of the control group of beef, on which they did not apply pressure, showed thin and thick filament ultrastructure and a normal sarcomere arrangement, there was no difference in the using of 130 MPa pressure for 260 seconds at 10°C compared to the control. • 325 MPa pressure did not cause a change in myofibril structure, but 520 MPa pressure caused a complete change in myofibril structure.	[51]
Cured ham and fillet	200 MPa (15-30 minutes) 300 MPa (15-30 minutes)	• Protein oxidation increased with increasing pressure and time.	[52]
Peccary meat (Tayassu tajacu)	100 - 400 MPa	• As pressure increased, shear force decreased and meat tenderness increased above 200 MPa. • HHP was effective in tenderizing the meat and having potential positive effects on color.	[53]
Asian hard clam (*Meretrix lusoria*)	200, 300, 400, 500, and 600 MPa for 3 minutes	• Clam meat became brighter and more transparent when the pressure was increased. • High pressure also significantly reduces the loads of aerobic plate count, psychotropic bacteria, coliforms, and *V. parahaemolyticus*.	[54]
Beef gels	200 MPa, 10 minutes, room temperature	• The total free amino acid content of beef gels was increased to 200 MPa. • 200 MPa was effective in producing beef gels while providing high quality textural and sensory properties.	[55]
Spanish chorizo sausage	349–600 MPa, 18°C	• Pathogen reductions increased with the pressure and duration of high hydrostatic pressure however pressures below 400 MPa did not lead to significant pathogen reductions.	[56]
Red abalone	200, 300, 400, and	• High hydrostatic pressure	[57]

muscle	500 MPa, 5 minutes	application improved abalone muscle protein digestibility. • The smallest changes in secondary protein structure were reported at 500 MPa.	

4. CONCLUSION

In recent years, with the increasing demand for ready-to-eat, easy-to-prepare, and minimally processed foods, new food quality and safety issues have emerged. To address these issues, approaches such as HHP through non-thermal processes are being investigated. High hydrostatic pressure can have both positive and negative effects depending on the type of product, the pressure conditions used (time, temperature, pressure level), and the other processing technologies with which it is used. This process extends the shelf life of food and provides microbiologically safe, higher quality products.
It is possible to largely avoid quality losses in terms of texture and sensory properties when microorganisms are inactivated using new technologies as an alternative to heat treatment. This is because heat treatment causes vitamins and antioxidants to degrade, which results in nutritional losses. Their importance is increasing day by day and they can meet the demands of consumers in recent years.

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