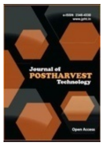

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REVIEW ARTICLE

# A review on high pressure processing of food

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## ABSTRACT

The quality and safety of food products are the two factors that most influence the choices made by today's increasingly demanding consumers. Conventional food sterilization and preservationmethods often result in a number of undesired changes in foods, such as loss of smell, colour, flavour, texture and nutritional value – in short, a reduction in the apparent freshness and quality of the final product. High-pressure (HP) processing, also sometimes known as high hydro- static pressure (HHP), or ultra high pressure (UHP) processing, is a relatively new non-thermalfood processing method that subjects liquid or solid foods, with or without packaging, to pres-sures between 50 and 1000 MPa. Extensive investigations have revealed the potential benefits of high pressure processing as an alternative to heat treatments. These benefits are apparent in various areas of food processing, such as the inactivation of microorganisms and enzymes, denaturation and alteration of the functionality of proteins and structural changes to food materials.

**Keywords:** Food processing, consumer, high pressure, pressure-shift, food safety

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## INTRODUCTION

Food processing involves the transformation of raw animal or plant materials into consumer-ready products, with the objective of stabilizing food products by preventing or reducing negative changes in quality. Without these processes, we would neither be able to store food from time of plenty to time of need nor to transport food over longdistances (Lund, 2003).

To consumers, the most important attributes of a food product are its sensory charac- teristics (e.g. texture, flavour, aroma, shape and colour). These determine an individ-ual's preference for specific products and minor differences between brands of similar products can have a substantial influence on acceptability. A goal of food manufacturers is to develop and employ processing technologies that retain or create desirable sensory qualities or reduce undesirable changes in food due to processing.

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Physical (e.g. heating, freezing, dehydration, and packaging) and chemical (e.g. reduction of pH or use of preservatives) preservation methods continue to be used extensively and technological advances to improve the efficiency and effectiveness ofthese processes are being made at a rapid rate. The basis of these traditional methodsinvolves reducing microbial growth and metabolism to prevent undesirable chemicalchanges in food. Probably the most common method of food preservation used today is thermal treatment (e.g. pasteurization, sterilization). Although heating food effect- ively reduces levels of microorganisms such as bacteria, such processing can alter the natural taste and flavour of food and destroy vitamins.

Therefore, alternative or novel food processing technologies are being explored and implemented to provide safe, fresher-tasting, nutritive foods without the use of heat or chemical preservatives. Innovative non-thermal processes for preservation of food have attracted the attention of many food manufacturers. In the search for new pro- cessing methods, particularly for certain products, the application of high-pressure (HP) processing has shown considerable potential as an alternative technology to heattreatments, in terms of assuring safety and quality attributes in minimally-processed food products (Palou et al., 2002).

## Description of the process

Industrial HP treatment is currently a batch or semi-continuous process. The selec-tion of equipment depends on the kind of food product to be processed. Solid food products or foods with large solid particles can only be treated in a batch mode. Liquids, slurries and other pumpable products have the additional option of semi-continuous production (Ting and Marshall, 2002). Currently, most HP machines in industrial usefor food processing are batch systems, whereby the product is placed in a high-pressure chamber and the vessel is closed, filled with pressure-transmitting medium and pressurized either by pumping medium into the vessel or by reducing the volume of the pressure chamber, for example by using a piston. If water is used as the pressurizing medium, its compressibility must be accounted for; water is compressed by up to 15 per cent of volume at pressures above 600 MPa. Once the desired pressure is reached, the pump or piston is stopped, the valves are closed and the pressure is main-tained without further energy input. After the required hold time has elapsed, the system is depressurized, the vessel opened and the product unloaded. The system is then reloaded with product, either by operators or machines, depending on the degree of automation possible (Ting and Marshall, 2002). The total time for pressurization, holding and depressurization is referred to as the ‘cycle time’. The cycle time and theloading factor (i.e. the percentage of the vessel volume actually used for holding packaged product, primarily a factor of package shape) determines the throughput ofthe system. In a commercial situation, with this sort of batch process, a short holdingtime under pressure is desirable in order to maximize throughput of product.

## Packaging requirement

HP processing requires airtight packages that can withstand a change in volume cor- responding to the compressibility of the product (Hugas et al., 2002), as foods decrease in volume as a function of the pressure applied, while an equal expansion occurs on decompression. For this reason, the packaging used for HP treated foods must be able to accommodate up to a 15 per cent reduction in volume and return to its original vol-ume without loss of seal integrity or barrier properties. Therefore, selection of pack- aging materials is very important. Plastic films are generally accepted for HP processing, although they are frequently not suitable for high temperature processing. On the other hand, metal cans and glassware are generally not suitable for HP treat- ment. Packaging materials which are oxygen-impermeable and opaque to light may be developed especially for keeping fresh colour and flavour of certain HP-treated foods (Hayashi, 1995).

In production, the use of flexible pouches can achieve high packing ratios; the useof semi-rigid trays is also possible; vacuum-packed products are ideally suited for HP.Since the size and shape of the product will have major effects on the stacking effectiveness of the product carrier, they must be optimized for the most cost-effective process; it is obviously uneconomical to treat empty space. Glass bottles or gable car- tons can be used for HP-processed foods if filling is performed after exposure to pressure. This further allows innovative package shapes and printing graphics (Ting and Marshall, 2002).

## Use of high pressure to improve food safetyand stability

The effectiveness of any food preservation technique is primarily evaluated on the basis of its ability to eradicate pathogenic microorganisms present and so to enhancethe product's safety; a secondary objective is inactivation of spoilage microorganisms to improve the shelf-life of the food (McClements et al., 2001). Growth of micro- organisms in foods can cause spoilage by producing unacceptable changes in taste, odour, appearance and texture. Microorganisms are a heterogeneous group of organisms, different members of which are capable of growth at temperatures from well below freezing (extreme psychrophiles) to temperatures above 100°C (extreme thermophiles). However, each species has a particular temperature range in which it can grow best; this range is determined largely by the influence of temperature on cell membranes and enzymes, and growth is restricted to those temperatures at which cellular enzymes and membranes can function. As with heat, large differences in pressure resistance can be apparent among various strains of the same species.

HP treatment is also known to cause sublethal injury to microbes, which is a par- ticularly important consideration for any preservation method. Given favourable conditions, such as prolonged storage in a suitable substrate, sublethally injured cells may be able to recover (McClements et al., 2001). On the other hand, cell death is associated with irreversible damage to cell components essential for cell growth and reproduction.

## High Pressure Regulations

Today, in most countries, food safety is tightly controlled by regulation and is a *sine qua non*. While many of the factors and microorganisms that can present hazards to the con- sumer are known and have been intensively studied, new and emerging pathogens not previously regarded as problematic continue to be identified. As already discussed, processors must also increasingly balance the need for assurance of food safety against consumer demand for minimally-processed products. For these reasons, emerging tech- nologie such as HP are of considerable interest and potential benefit to the food industry. However, before the implementation of new preservation technologies, several issues need to be addressed, such as the mechanisms of microbial resistance and adapta- tion to these new technologies, the mechanisms of microbial and enzyme inactivation, the identification of the most resistant and relevant microorganisms in every food habi- tat, the role of bacterial stress, the robustness of the technologies, the increased safety rela- tive to existing technologies and, last but not least, the legislation needed to implement them (Hugas et al., 2002).

All new pressure vessels to be used in the EU have to comply with the 'Pressure Equipment Directive' (PED) regulation, which came into force in 2002. This regulation is an extension of the 'CE' safety standard already employed in the EU and now rec- ognized world-wide. As pressure vessels of all types utilize potentially hazardous energy, the PED regulation seeks to identify good design, good manufacturing practices anddetailed safety assessment for safe operation and maintenance of the vessels and auxiliary parts.

## Applications of high pressure

Water has many physical and chemical properties that are significantly affected by pressure (Otero et al., 2002). Pressure opposes reactions associated with volume increase, such as freezing of water at atmospheric pressure. This forms the basis of a new fieldof HP food applications, such as high-pressure freezing, thawing and storage of foodat temperatures below 0°C without freezing. Recently, the effect of pressure on the water–ice equilibrium has attracted the attention of many food technologists and engineers studying the freezing and thawing of foods. This area was reviewed in detail in Denys et al. (2002).

**High pressure freezing applications**

Freezing has long been established as an excellent method for preserving food products, with the potential to allow high retention of food quality over long storage periods. Generally, freezing preserves the taste, texture and nutritional value of foods better than any other preservation method; as a result, ever-increasing quantities of food are being frozen throughout the world. The main potential disadvantage of freezing foods is the risk of damage caused by the formation of ice crystals; the formation of ice crystals mechanically damages cell structures in tissue-derived food products (e.g. fruit, vegetables, meat) by puncturing cell walls and distorts the tissue structure, as well as inducing protein denaturation. The size and location of ice crystals formed during freezing depend on the rate of freezing and the final temperature of the process and affect important quality parameters such as texture and colour of the frozen products and exudation of moisture (drip loss) on thawing (Martino et al., 1998).

It is well-known that a fast freezing rate results in a fine ice structure, with intensive nucleation and the formation of high numbers of small ice crystals, which causes less damage to the structure of the product than slow freezing rates that favour the formation of large ice crystals; rapid freezing of food is thus preferred (Thiebaud et al., 2002). In the past few years, HP processes in which phase transitions take place, such as pressure shift freezing (PSF), have attracted the attention of many researchers.

In traditional freezing processes (such as air blast, plate contact or cryogenic systems), when food comes into contact with the refrigerating medium, ice nucleation occurs inthe region next to the refrigerated border and is controlled by the magnitude of supercooling reached in this zone. Supercooling (the difference between the actual temperature of the sample and the expected solid–liquid equilibrium temperature at a given pressure) is the driving force for ice nucleation and is an important parameter that con-trols the size and number of ice crystals formed (Chevalier et al., 2000). Burke et al. (1975) stated that, for each degree K of supercooling, there is an increase of about ten-fold in the ice nucleation rate. The thermal gradient existing between an interior point in a food product and the surface determines to a great extent the local cooling/freezing rate of the sample. The freezing rate decreases towards the centre of the product and is particularly important in large volume products (Sanz et al., 1999). In inner regions of products being frozen, because of the thermal gradients, supercooling to produce ice nucleation may not be achieved, resulting in the growth of undesirably large ice crystals.

The principle of pressure shift freezing (PSF) involves reducing the temperature of a food sample, held in an HP vessel whose temperature is regulated at sub-zero temperatures, to below 0°C under pressure. The food sample is typically cooled to —20°C at200 MPa, at which pressure the water remains in a liquid state. The vessel is then depressurized, the pressure rapidly returns to atmospheric pressure and the sample undergoes a sudden temperature rise to the phase change temperature at the current pressure; partial freezing is initiated during this phase due to high supercooling of the sample. The temperature increases according to the temperature–pressure equilibriumrelationship of liquid water and ice I (Chevalier et al., 2000). Sanz et al. (1997) showed that the ratio of ice:water can reach 0.36 for a sample of pure water at the end of the pressure release step, indicating that only partial freezing can be obtained during PSF. Freezing must thereafter be completed at atmospheric pressure.

### High pressure thawing

Thawing generally occurs more slowly than freezing, potentially allowing further damage to food products. Therefore, the thawing of frozen food products is a particu-larly important stage of the handling of frozen food products, in particular in terms ofminimizing the amount of proteinaceous exudate (drip) lost from many food products(e.g. meat, fish) on thawing. The loss of such fluid generally reduces the eating quality, binding ability and weight of food, all factors contributing to its quality and value. Thevolume of drip produced on thawing has been shown to be closely related to the rateof freezing (Kalichevsky et al., 1995), which in turn is related to the size and locationof ice crystals in frozen foods (Chevalier et al., 2000). To prevent microbial growth, the temperature for this stage should be less than 4°C; under such conditions, thawing times are very long, and processes to reduce this time are consequently of great interest. Recently, a promising route involving, once again, the effect of pressure on the melt- ing point of water, has been identified. This HP method permits not only control of thethawing time, but also control of the ice front propagation dynamics, which presentssignificant advantages for maintaining food quality.

When HP treating a frozen sample to induce thawing ('high-pressure thawing'), thetransition to the non-frozen state occurs at a high pressure and an introduction of a pressure-related latent heat seems necessary (Denys et al., 2000). Preliminary studies have revealed that thawing under HP preserves food quality and reduces thawing times (Denys et al., 2000). Knorr et al. (1998) and Otero and Sanz (2003) distinguished between processes of pressure-assisted and pressure-induced thawing. In the former, the phase transition (ice to water) occurs at constant pressure by increasing the temperature, while in the latter the phase change is initiated by a pressure change and proceeds at constant pressure.

### Outlook for high pressure processing of food

Consumers are changing their food consumption and purchasing behaviour; premium product sales, restaurant spending and ready-to-eat food spending are all increasing world-wide, as are health- and nutrition-driven product sales. New technologies such as HP can allow producers to create new markets not possible with old technologies and such benefits are only now being exploited. Consumers are generally willing to pay more for greater perceived value (Ting and Marshall, 2002). Adoption of new technologies for food preservation and processing is traditionally a slow process. However, the food industry is today seeking new technologies to enhance the safety, nutritional quality and sensory quality of food products. In the near future, the range of new non-thermal technologies will very likely complement current technolo-gies, or even replace them for certain food products.

The commercial feasibility of any technology depends ultimately on business prof-itability. The production cost of a process must, of course, be lower than the value added to the product. The value added by HP can be measured in terms of higher product quality, increased safety and longer shelf-life. These issues can further translate into reduced transportation, storage, insurance and labour costs, consumer convenienceand enhanced safety. Fundamentally, the strategy for superior products is based on ahigher perceived added value rather than on absolute cost (Ting and Marshall, 2002).The use of HP as a possible alternative processing method to thermal treatment has brought about the need to study the pressure–temperature behaviour of macromolecu-lar food ingredients since, for example, the mechanisms of protein denaturation under pressure are far from fully understood. It is well known that HP can modify the activity of some enzymes and the structure of some proteins. Although covalent bonds are not affected, hydrogen bonds as well as hydrophobic and intermolecular interactions may be modified or destroyed. From thisperspective, some concern about the potential risks of HP may arise. It is necessary tocompile data in order to clarify the role of HP towards toxicity, allergenicity, loss of digestibility and the eating and nutritional quality of foods (Hugas et al., 2002). However, no studies to date have revealed any evidence that this could pose a problem for HPP.

## CONCLUSION

The application of any new technology presents significant challenges to food tech- nologists and food researchers. HP processing offers the food industry a technology that can achieve the food safety of heat pasteurization while meeting consumer demand for fresher-tasting minimally-processed foods. In addition, other favourable organolep- tic, nutritional and rheological properties of foods have been demonstrated following HP, in comparison to heat processing. The retention of colour and aroma and the preservation of nutritive components are enormous benefits to both the food processing industry and consumers. Also, from a food processing/engineering perspective, key advantages of high-pressure applications to food systems are the independence of size and geometry of the sample during processing, possibilities for low temperature treatment and the availability of a waste-free, environmentally-friendly technology. Application of HP caninactivate microorganisms and enzymes and modify structures, while having little or no effects on nutritional and sensory quality aspects of foods. HP food processing is today being used on an ever-increasing commercial basis. Opportunities clearly exist for innovative applications and new food product develop- ment. HP can affect the functionality of protein and carbohydrate molecules in oftenunique ways, which may allow the optimization of food manufacturing processes and the production of novel foods. The range of commercially-available HP-processed productsis relatively small at present but there are opportunities for further development and the production of a wide range of HP-treated products. The main drawbacks of pressure treatment of solid foods are the use of batch or semi- continuous (the latter for liquids only) processing and the high cost of pressure vessels. HP is an environmentally-friendly, industrially-tested technology that offers a naturalalternative for the processing of a wide range of different food products. This methodprolongs product shelf-life while at the same time preserving organoleptic qualities, by inactivating microorganisms and enzymes while leaving small molecules such as flavours and vitamins intact. It is a technology with many obvious advantages, especially for food products with a high added value, targeted at a growing group of consumers that demand maximum safety and quality in the products they purchase.

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