High pressure processing as a method for decontaminating poultry

A.H. DINÇER BAYSAL¹ and T. BAYSAL²*

¹Department of Food Engineering, Izmir Institute of Technology, 35430 Urla-Izmir, Turkey
²Department of Food Engineering, Ege University, 35100 Bornova-Izmir, Turkey
taner@food.ege.edu.tr

Keywords: decontamination; poultry; high pressure; food-borne pathogen

Summary
Means of controlling or even improving the safety of food products is to decontaminate the carcasses or products during or at the end of the production line. The decontamination of meat and poultry can help to reduce human food-borne infections. However, process hygiene to prevent contamination should never be neglected. High pressure processing of decontaminating poultry meat products are discussed in this review.

Introduction
Food and drink manufacturers have in recent years turned their attention to novel preservation processes in order to satisfy the consumer's demand for additive-free food and drink products with sensory attributes which resemble their fresh non-preserved counterparts yet shelf lives which enable low cost distribution and life-style convenience. Examples of such technologies include irradiation, microwave and ohmic sterilization and “natural” antimicrobial agents. It is not surprising that food technologists have turned their attention to high pressure energy as a mechanism for destroying microorganisms in foods without affecting the complex chemistry which controls sensory quality. High pressure processing (HPP), also described as high hydrostatic pressure (HHP), or ultra high pressure (UHP) processing, subjects liquid and solid foods, with or without packaging, to pressures between 100 and 1000 MPa. Process temperature during pressure treatment can be specified from below 0°C to above 100°C.

High pressure food processing
High pressure food processing generally relies on the application of isostatic, hydraulic pressures in the range of 100 to 1000 MPa. The process can be carried out in any type of hydraulic fluid but water is often preferred for ease of operation and compatibility with food materials. There is some evidence that compressed gases could be useful for food preservation but from an engineering viewpoint only comparatively low pressures (<50 MPa) can be used because of the extreme energies contained within pressurized gas systems and the hazards associated with pressure vessel explosion. Liquids such as water are relatively incompressible and store much less energy in their compressed state compared with gases: the risk from explosion is thus greatly reduced by the use of incompressible fluids as the pressurizing medium. Liquid foods can be compressed directly in a pressure vessel or liquid and/or solid foods can be contained in flexible containers immersed in the hydraulic fluid for the duration of the pressure process.

High pressure and food microbiology
Microbes vary in their sensitivity to high pressure (HP). In general, vegetative cells are sensitive to pressures over 100 MPa and die rapidly at pressures in excess of 500 MPa but there are many exceptions to this rule. The rate of vegetative cell death rarely follows first order kinetics and in many cases pronounced survivor tails are seen in log survivor versus time graphs. These “tails” give rise to practical problems if manufacturers are considering the development of processes to sterilize food or eliminate pathogens. The chemical and physical environment can affect the effectiveness of high pressure inactivation. Of particular importance is the amount of free water present in a food: in
general, at least 40% free water is needed to achieve killing of vegetative microbes. The technique is thus not suitable for the decontamination of dry materials. Bacterial spores are very resistant to pressure and the application of pressures in excess of 1000 MPa for several hours will not affect significantly the levels of spores found in some types of foods. Bacterial spores appear to show increased sensitivity to pressure if the temperature is elevated to greater than 40°C and research is currently under way to assess the commercial feasibility of this approach. Spores can also be germinated using HP and there might be some advantage in using pressure to initiate germination and render the resulting vegetative cells sensitive to a later pressurization cycle or some other mechanism of inactivation. The effects of HP on food microbiology have been well reviewed in recent literature (Earnshaw, 1995; Knorr, 1995; Isaacs et al., 1995; Patterson et al., 1995).

The main reasons for interest in HPP are:
- High-quality minimally processed food can be produced.
- A potential for microbiologically safe and additive-free food.
- Possibilities for HPP on a semi-continuous basis.

HP inactivates microorganisms and some enzymes, and induces texture changes. These effects are associated with volume reductions, changes in pH equilibrium and solubility constants. This action tends to affect secondary bonds and hence tertiary structure properties of large molecules. DNA replication and cell membrane structure will be affected (protein denaturation), whereas small molecules are left relatively unaffected (amino acids, flavours, vitamins, pigments). The presence of water in foods to be used in HPP is essential (at least 40% w/v water) for the process to be effective; HPP does not work with dried foods. Several workers have reported that there is a faster rate of kill of microbial vegetative cells using high pressures at lower temperatures (i.e. at 5°C rather than room temperature).

As well as preservation effects, HP can be used to improve the preparation and processing of foods along the following lines (Mertens, 1992):
- Accelerate protein gel formation without flavour or colour loss.
- Freezing without ice-crystal formation.
- Change enzyme specificity.
- Tenderization of meat (1000 to 1500 bar at 60°C).
- Improve starch digestibility.
- Simplify the preparation of jams (4000 to 6000 bar at room temperature for 10-30 min, refrigerate for a two-month shelf-life).
- Rapid tempering of chocolate (two treatments of 5 min. at 1500 bar and 31°C).

Lower-range HP treatment, the use of a single-step HP homogenization stage (40 MPa to 160 MPa) at room temperature and in combination with a pre-treatment, using chitosan or lysozyme, has resulted in higher reduction in the numbers of Escherichia coli, Streptococcus lactis and Bacillus subtilis, when compared with samples which received only the homogenization. This is part of a HP research programme taking place at the Berlin University of Technology (1992). The advantages of HPP over other methods of food preservation, particularly those involving heat, are numerous; for example, instantaneous effect of pressure throughout the food; ability to operate at low or ambient temperatures, lack of chemical additives, and the production of preserved foods with a natural or raw flavour; pressure treatment could also prove a useful technique for reducing microbial loads of chilled foods. However, the survival of heat-resistant spores and pathogens after treating at HP is still an area for concern. Results on bacterial spore and virus inactivation are inconsistent, and more work is required to clarify the relationship between bacterial spore inactivation with combined pressure and temperature treatments. Hoover et al. (1989) found that spores of Clostridium perfringens could be inactivated by very HP and temperatures of the order of 100°C. HPP offers a number of advantages over conventional thermal processing. For example, HP inactivates spoilage and pathogenic bacteria, but vitamins, colour and flavour remain largely unaffected (Kimura et al., 1994; Thakur and Nelson, 1998). This allows the production of wholesome foods, with little loss in nutritional and sensory qualities (Tewari et al., 1999). Furthermore, HP treatment is an isostatic process and pressure is transmitted instantaneously and uniformly, independent of the size or shape of the food (Smelt, 1998).

There is, therefore, no likelihood of over-treating the outside of the food in order to ensure that all parts of the food have been adequately processed, as may occur in thermal processing. HP also offers the potential to modify the functional properties of some food constituents (Hoover et al., 1989). This may allow new foods to be produced or improvements made to existing processes, e.g. reduction of rennet coagulation time, improved acid-set gels, faster tempering chocolate, formation of gels at low temperatures, improved restructured meat products, tenderisation of meat and pressure-induced gels of meat or fish protein (Johnston, 1995; Mozhaev et al., 1994).
The high initial capital outlay and the relatively low throughput mean that the products most suitable for HPP are high quality, niche-market foods for which the consumer is prepared to pay higher price. Value-added poultry products fulfil these criteria and offer possibilities for HPP. HP may also have technological advantages over conventional processes when used to produce further-processed poultry products. For example, sausages made with pressure-treated poultry meat had a better texture and were more juicy after cooking than those produced using untreated meat (Yuste et al., 1999). However, more work is required to determine the effect of HP on shelf-life extension and to determine the microorganisms responsible for spoilage after pressure treatment.

**Decontamination of poultry by high pressure processing**

The various effects of HPP can be grouped into cell envelope related effects, pressure induced cellular changes, biochemical aspects, and effects on genetic mechanisms. It has been established that cellular morphology is altered by pressure, and that cell division slows with the application of increasing pressures (Farkas and Hoover, 2000). The effectiveness of HP against pathogens in foods is well documented (Patterson et al., 1995; Shigeihisa et al., 1991; Smelt, 1998). The combination of HP treatment and storage under low temperature conditions should control pathogens. For example, vacuum packaging may allow *Clostridium perfringens* to grow but this species can be controlled using effective refrigeration, as it can not multiply at less than 15°C (ICMSF, 1998). Similarly, the growth of *E.coli* O157:H7 (and other EHEC strains), *Campylobacter* and most *Salmonella* is inhibited at refrigeration temperatures (Doyle, 1990; Upmann et al., 2000). Styles et al. (1991) reported a >7-log reduction in *L. monocytogenes* Scott A after 20 min at 3400 atm (approx. 340 MPa) and Patterson et al. (1995) found a >7-log reduction in *L. monocytogenes* at 400 MPa for 15 min. Wei et al. (1991) used 13.7 MPa for 2 h at 35°C to kill inoculated *S. typhimurium* in chicken. Levels of microbial reduction varied considerably depending on the nature of the food and treatment conditions. Bacterial reductions ranged from limited effect to 9 log units (Farkas and Hoover, 2000). Crawford et al. (1996) were able to eliminate *C. sporogenes* in chicken breast using combinations of HPP and gamma irradiation (GI). Paul et al. (1997) targeted staphylococci in lamb meat. A population of approximately 10⁶ staphylococci per g was reduced by only 1 log unit by either treatment with GI (1 kGy) or HPP (200 MPa for 30 min). When used in combination, no staphylococci were found immediately after completion of the tandem process. After 3 week of storage at 0 to 3°C, mannitol negative staphylococci (presumably coagulase negative as well) were detectable (<10⁵ cfu per ml). Patterson and Kilpatrick (1998) used HPP against *E.coli* O157:H7 NCTC 12079 and *S. aureus* NCTC 10652 in milk and poultry. Their findings showed a practical necessity for combined use of pressure and elevated temperatures. Alone neither treatment displayed effective inactivation of the pathogens. In minced irradiation sterilised poultry meat, *E.coli* was reduced by approximately 6 log cfu per g by 400 MPa/50°C/15 min, and *S. aureus* exposed to 500 MPa/50°C/15 min was reduced by approximately 5 log cfu per g. HPP of *L. monocytogenes* and *S. typhimurium* in fresh pork loin was investigated by Ananth et al. (1998), who found that at 25°C the D values at 414 MPa were 2.17 min for *L. monocytogenes* and 1.48 min for *S. typhimurium*. A treatment of 414 MPa/13 min/25°C inactivated either pathogen inoculated at levels of approximately 10⁶ per chop. The effects of HPP on *L. monocytogenes* and pork chops were also studied by Mussa et al. (1999) with pressure treatments apparently conducted at ambient temperature. Strain Scott A was found to have a D value at 400 MPa of 3.5 min while the indigenous microorganisms of pork was found to have a D value at 400 MPa of 1.3 min. Spoilage of chicken generally occurs when the aerobic plate count reaches 10⁷-10⁸ CFU/g, which is usually after 4-10 days depending on conditions at slaughter, the types and numbers of bacteria initially present and their growth rates and on packaging and storage conditions (Jimenez et al., 1997; Sawaya, Abu-Ruwaidia; Upmann, Paulsen, James and Smulders, 2000). Chicken meat is a highly nutritious medium, which spoils quickly. The higher the initial microbial load on the chicken shorter the shelf-life (Geornaras et al., 1994). Vacuum-packaged, minced chicken was pressure treated at 500 MPa for 15 min at 40°C and stored at 3°C. Aerobic plate counts, psychrotrophic counts and anaerobic counts increased rapidly in untreated chicken during storage and reached 10⁷ CFU/g after approximately 8 days at 3°C; however, these counts did not increase significantly (P>0.05) in pressure treated chicken during 182 days of storage at 3°C (Linton et al., 2004).
Conclusion
The control of process and product hygiene in poultry and meat processing plants is of the utmost concern from both a public health and commercial point of view. Hygiene intervention in the process alone does not lead to safe products, owing to the constant flow of bacteria into the processing plant and the unavoidable occurrence of cross-contamination. The decontamination of carcasses or meat products therefore seems to be the only possible intervention technique. Product decontamination during or at the end of the process can be carried out by chemical or physical methods or combinations of the two types. Methods for meat decontamination in use today, such as steam vacuuming, carcass washing with hot water or steam, application of antimicrobial chemicals, and combinations of these technologies have been widely researched and have been proven effective at reducing bacterial levels. Raw meat products continue to have a low level of contamination with enteric bacteria which may include pathogens of concern to human health. This fact requires that industry must continue to seek new and better methods of implementing existing technologies, while at the same time support research to find new and promising ways to continually enhance the safety of fresh meat products. Future research on decontamination treatments should focus on safe applications that do not result in residues on products, thereby facilitating consumer acceptance, no unacceptable risks to the product and the environment, and must be a low cost application. Clearly the use of HP combined with vacuum packaging and effective cold storage is a very useful tool to enhance the microbiological quality of minced chicken. However there may be changes in appearance and texture of minced chicken, which would have to be considered when developing new products. Combinations of HP with mild heat treatment and/or preservatives are more promising alternatives. Killing bacteria by UHP treatment is a physical approach. A pressure of up to 600 MPa is necessary to kill gram-positive bacteria. Being a batch process, its application in the meat industry, especially for beef or pork carcass decontamination, although equipment with chambers that have a capacity of up to 1000 litres is available. Small carcasses, such as poultry, or sausages, hams and other meat products or ground meat such as mechanically deboned poultry meat or surimi-like slurries can be treated with this technique. However, discoloration of the products may occur. Other applications of this technique, such as decontamination of process water, can be taught. Although some of the treatments listed above have been investigated in combination with others (e.g. ultrasonic and HP with raised temperature) there is plenty of scope for investigating other synergistic effects. Of particular interest for the raw meat industry would be to investigate combinations of acid or TSP dips or sprays with electromagnetic waves, (or ultrasonic for poultry) and possibly the effect of air ions during chill-storage of red meat. In the future, microwaves may be combined with conventional heating or chemical treatments for surface treatment in meat processing.

References


SMELT, J.P.P., 1998Recent advances in the microbiology of high pressure processing. Trends in Food Science and Technology 9: 152–158.


