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Review

Quality considerations with high pressure processing of fresh and value added meat products

Bajo Bajovic, Tomas Bolumar, Volker Heinz *

German Institute of Food Technologies, Prof.-von-Klitzing-Str. 7, D-49610 Quakenbrück, Germany

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A B S T R A C T

Pressure can be applied by high hydrostatic pressure, better known as high pressure processing (HPP), or by hydrodynamic pressure (HDP) in the form of shockwaves to alter quality parameters, such as shelf-life and texture of meat and meat products. The aim of this review is to give an overview of the use of pressure in the meat industry and to highlight its usage as a method to inactivate microorganisms but also a novel strategy to alter the structure and the quality parameters of meat and meat products. Benefits and possibilities of the technologies are presented, as well as how to overcome undesired product changes caused by HPP. The use of hydrodynamic shockwaves is briefly described and a promising newly developed industrial prototype for the generation of shockwaves by underwater explosion is presented.

Contents

1. Introduction

High pressure processing (HPP) in the meat industry is mainly used to increase the shelf-life and to improve the food safety of ready-to-eat (RTE) meat products as a novel post-packaging non-thermal decontamination technology. The application of HPP to meat and meat products results in a modification of quality parameters such as color, texture and water holding capacity. Alterations have no negative impact on the nutritional value. Therefore, it can be employed as a new dimension in product development. HPP has become an industrial reality for the meat industry within the past twenty years.

The use of HPP for meat and meat products has been extensively described in different book chapters (Atsushi, Ken, Hiroyuki, Tadayuki, & Yoshihide, 2006; Garriga & Aymerich, 2009; Hendrickx & Knorr, 2002; Ikeuchi, 2011), in a growing number of reviews targeted to specific topics (Bermúdez-Aguirre & Barbosa-Cánovas, 2011; Campus, 2010; Cheftel & Culioli, 1997; Patterson, 2005; Sun & Holley, 2010) and in an increasing number of scientific research papers. HPP is commercially used mainly as a non-thermal decontamination technology for processed and RTE meat products with high consumer acceptance, in comparison to other non-thermal decontamination technologies such as ionizing radiation. This fact is leading to an increased number of commercial installations.

In addition, pressure can also be applied to meat in the form of hydrodynamic pressure treatments in order to induce mechanical tissue

* Corresponding author. Tel.: +49 5431 183 0; fax: +49 5431 183 114.
E-mail address: v.heinz@dil-ev.de (V. Heinz).

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disintegration and therefore tenderize meat. The present article provides an overview of the application of hydrostatic (HPP) and hydrodynamic (HPD) pressure treatments and their impact on the quality parameters of meat and meat products.

2. High hydrostatic pressure (HPP)

The response of vegetative pathogenic and spoilage microorganisms in meat and meat products to HPP is variable and depends on process parameters such as pressure, temperature and processing time and on product parameters such as pH, a_W, salt content and the presence of other antimicrobials (Rendueles et al., 2011; Töpfl & Heinz, 2009). HPP as mentioned is mainly used in a commercial environment as an effective post-packaging decontamination technology for RTE meat products particularly in cases where heat treatment is not possible or convenient. Pressure levels applied for the pasteurization of meats and meat products, range in an area of 400–600 MPa with short processing times of 3–7 min and at room temperature. These treatments lead in most cases to an inactivation of more than four log units for the most common vegetative pathogenic and spoilage microorganisms resulting in an increased shelf-life and improved safety. An overview of the commercially available "pressurized" meat products and companies applying HPP is presented in Table 1.

The majority of the commercial available meat products belong to RTE food category, and only one fresh meat product, minced beef, which is further processed before its consumption is available in the pressurized form in the market so far (Table 1). HPP affects quality parameters of fresh meat, particularly depending on the pressure level applied, and thus typical characteristic associated with fresh meat like texture and especially color can be remarkably modified. The meat becomes more gel-structured and paler losing the typical appearance of fresh meat.

Depending on the process parameter applied, high pressure treated meat would possibly not be recognized as fresh meat by consumers. Under EU regulation "fresh meat" has not undergone any preserving process other than chilling, freezing or quick-freezing, including meat that is vacuum-wrapped or wrapped in a controlled atmosphere (The European Parliament and the Council of the European Union, 2004). Overall, the color change induced by HPP in the meat as well as the current legal definition of fresh meat has drastically limited the use of HPP for fresh meat in the markets.

An overview of different publications dealing with quality considerations of fresh and processed meat products is given in Table 2.

2.1. Effect of HPP on the inactivation of microorganisms

Moderate level of pressure (10–50 MPa) decreases the rate of growth and reproduction, whereas higher level of pressure causes inactivation (Rademacher, 2006). A brief overview of the required pressure level for the microbial inactivation of different microorganisms in meat and meat products is demonstrated in Table 3. The basic principles of HPP microbial inactivation are based on protein denaturation which results in enzyme inactivation (Barbosa-Canovas, Pothakamury, & Swanson, 1995), and the agglomeration of cellular proteins (Farr, 1990). The change of the permeability of the cell membrane however results from the crystallization of fatty acids from phospholipids (Cheftel & Culioli, 1997). The cell membrane is constructed as a bi-layer of phospholipids and high pressure causes a phase transition and as a consequence the membrane is destabilized and the permeability is negatively affected (Hazel & Williams, 1990; Shimada et al., 1993). Further, the inactivation could be linked to protein denaturation resulting in the dissolution of membrane bound enzymes (Hoover, Metrick, Papineau, Farkas, & Knorr, 1989; Smelt, 1998). The partial inactivation of enzyme systems by high pressure leads to a breakdown of metabolic actions in biological systems (Knorr & Heinz, 2001).The protein denaturation depends on such external factors as pH, salt content, water activity (a_W) and the presence of other ingredients like sugars (Molina-Höppner, Doster, Vogel, & Gänzle, 2004; Smelt, 1998). Aside from the product parameters, the processing conditions: pressure (P), temperature (T) and time (t) have a decisive importance on the inactivation of living cells. In the high temperature domain, it is generally accepted that pressure and temperature act synergistically on the inactivation of vegetative bacteria (Heinz & Buckow, 2010). For the majority of microorganisms, the highest pressure tolerance is found between 20 and 30 °C. In the case that lower temperatures are applied the stability is decreased (Buckow & Heinz, 2008). Inactivation depends on a number of factors related to the Gram type, physiological state and strain particularities (Jofré, Aymerich, Bover-Cid, & Garriga, 2010). Bacterial resistance to high pressure is highly variable even among strains of the same species (Liu, Betti, & Gänzle, 2012). Among the pressure resistant species, Gram-positive bacteria such as *Staphylococcus aureus*, as well as Gram-negative bacteria such as *Escherichia coli* can be found (Benito, Ventoura, Casadei, Robinson, & Mackey, 1999; Jofré et al., 2010; Liu et al., 2012). Combination of elevated temperatures (>50 °C) with pressure has also been proposed to overcome the problem of pressure resistant strains (Patterson, 2005).

Application of combined hurdles together with HPP has been proposed to increase the microbicidal effect of low pressure processes in order to minimize the unwanted changes induced by ultra-high hydrostatic pressures (above 400 MPa) in meat and meat products. Synergistic effects with HPP have been described with antimicrobials, low pH, carbon dioxide, vacuum packaging and chilled storage (Garriga & Aymerich, 2009). Several examples of combinations of HPP treatments with additional preservation methods are listed in Table 2. Moreover, additional hurdles or processes are useful to avoid the recovery of sublethal injured cells (Jofré et al., 2010; Liu et al., 2012).

Nevertheless, optimization of process parameters is required and depends on specific testing of the particular application. Shelf-life

Table 1
Examples of commercially available meat products and companies using HPP.

Country (year)	Company	Product	Source
Romania (2011)	Chris Tim	Fermented sausages	(Cris-Tim, 2012)
Netherlands (2010)	Zwaneberg	Filet American	(Hiperbaric, 2012)
		Steak Tartar	(Zwaneberg, 2010)
		Carpaccio	(Zwaneberg, 2012)
USA (2011)	Cargill	Hamburger (Fressure®)	(Cargill, 2011)
Greece (2010)	Creta Farm	Deli meats infused with extra virgin olive oil	(Hiperbaric, 2012)
USA	Perdue Farms	Poultry strips	(Ikeuchi, 2011)
Greece (2010)	Ifantis	Sliced processed meat (mortadella, ham, and salami)	(Ifantis, 2009)
USA	Tyson Food	Oven roasted chicken	(Ikeuchi, 2011)
UK (2011)	Deli 24	Meat and cheese snack products	(Watson, 2011)
USA (2001)	Hormel	*Natural Choice Product range®*	(Hormel, 2012)
USA (2011)	Columbus Foods	Deli meat & fermented meats	(Foodprocessing-Technology, 2011)
Spain (2002)	Campofrio	Thick sliced ham, chicken and turkey products, cooked and Serrano ham, chorizo	(Ikeuchi, 2011)
Canada	Santa Maria Foods	Sliced dry cured meat and cooked meats	(Hiperbaric, 2012)