Technology and trends on sterilized meat products

Tendências e tecnologia dos produtos cárneos esterilizados

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ABSTRACT
An adequate retort treatment enables extended shelf life and nutrient retention on meat products. Nonetheless, heat can cause loss of physico-chemical and sensorial properties according to processing and storage. Alternatively, high hydrostatic pressure is a non-thermal technology that reduces microbial loads, and has been increasing its global value market in food processing, including the meat sector. This review aims to ponder the commonly heat processing and the new technology of high hydrostatic pressure, where both has pros and cons outcomes in processed meat products.

Key words: high pressure processing; meat; microbial inactivation; retort.

RESUMO
O tratamento adequado promove extensão do tempo de prateleira e retenção de nutrientes nos produtos cárneos. No entanto, o calor causa prejuízos nas características físico-químicas e sensoriais, que variam conforme o processamento e armazenamento. Alternativamente, alta pressão hidrostática é uma tecnologia atérmica que reduz a carga microbiana, e tem ganhado o valor no mercado global de processamento de alimentos, inclusive no setor cárneo. Essa revisão tem como objetivo comparar o processamento térmico e a tecnologia de alta pressão hidrostática, considerando as respectivas características favoráveis e desfavoráveis de produtos cárneos processados.

Palavras-chave: alta pressão hidrostática; carne; inativação microbiológica; autoclave.

1 INTRODUCTION
Food safety is a significant concern for food processors and consumers worldwide. Only in USA, products with meat caused more than 2200 illnesses and 145 hospitalizations from 2012-2015 (CDC, 2017). Mostly, contamination occurs due to inadequate hygienic conditions and handling in
slaughterhouses (SCHLEGELOVÁ et al., 2004). Moreover, the attachment properties and the biofilm formation of bacteria on surfaces facilitate cross-contamination (KOO et al., 2013).

Contamination sources can be found in feeding water for carcass washing and meat handling (Bizani and Brandelli 2001). Osman et al. (2012) isolated Aeromonas from 5.9% of fresh and 5.2% of frozen samples from beef, buffalo or mutton. An epidemiological study in Belgium found that 10 out of 18 commercial broiler flocks received a salmonella positive status. Overall, 47% of the carcasses were infected.

In order to achieve a safe and palatable product, cooking is essential (TORNBERG, 2005), along with good manufacturing practice (EFSA 2015). An adequate heat treatment (cooking and other processing techniques) is necessary to destroy critical microorganisms in the product, indicating that all harmful microorganisms are reduced to a harmless level (INCZE et al., 1999). From the sensorial aspects, heating also leads to texture, tenderness and flavor modification by protein denaturation (TORNBERG, 2005). In addition, cooking results in production of volatile, odorous lipid oxidation products and, along with Maillard reaction products, form other volatiles which contribute to odor and flavor (WOOD et al., 2004).

An increase on elderly population, the demand for more healthy and additive-free but maintaining nutritious and natural foods are key factor that lead industries to develop new technologies to produce ready-to-eat foods (RTE), which includes attributes as convenience, safety and accessible products to consumers (DE BARCELLOS et al., 2010; GANAN et al., 2013).

A good number of treatments, such as pH and water activity depressors (salts, sugars) and antimicrobials are used to produce shelf stable products by the meat industry. One way to assure stability and provide long term shelf life lies on thermal inactivation, whereas retorting is the most popular (BARBOSA-CÁNOVAS et al., 2014). However, other technologies are available, e.g. active packaging, ohmic resistance, irradiation among others (AWUAH; RAMASWAMY; ECONOMIDES, 2007; AYMERICH; PICOUET; MONFORT, 2008; CHEN et al., 2012).

On the other hand, heat treatment produces some negatives effects like lipid oxidation, which is the main reason for undesirable odors, rancidity and also affects cholesterol oxides formation (BRONCANO et al., 2009). According to Baggio and Bragagnolo (2006) time and temperature are determinant factors on the rate of oxidation. By increasing free radical production, heat treatments form protein oxidation (which is the covalent modification of a protein induced either by reactive oxygen species or reaction with secondary products of oxidative stress) and also cause protein aggregation (TRAORE et al., 2012). Barbosa-Cánovas et al. (2014), states also that texture, taste, flavor and nutritional value have a significant reduction due to harsh processing condition of intense heat.
Alternatively, high pressure processing (HPP) is a non-thermal technology able to diminish the microbial load while preserving most of the sensory, nutritional and functional properties of processed food (Rivalain et al. 2010). HPP is performed at room temperature, reducing energy consumption associated with heat and cooling when compared with traditional thermal processing technology (RASTOGI et al., 2007). In addition, some studies achieved satisfactory results using HPP and mild heat treatments (ATES et al., 2014; SIKES; TUME, 2014).

There are a range of pressure-treated food products already on the market, including fruit preparations, juices, rice cakes, oysters etc.; also, HPP can be used for the development of new products or to increase the functionality of some ingredients. Therefore, in areas such as: packaging systems; natural antimicrobial substances; selective enzymatic inactivation; new meat products based on cold starch gelification; non-thermal protein coagulation can serve of experimentation by the meat sector with HPP (HUGAS; GARRIGA; MONFORT, 2002).

2 LITERATURE REVIEW
2.1 RETORT TECHNOLOGY AND TRENDS

Retort-processed pouch products, also known as commercial sterilization or autoclaving (HELDMAN; HARTEL, 1999), have the highest and the greatest potential to maintain acceptability, in addition to safety and nutritive value, for 3 to 5 years. While the technology still relies on severe application and penetration of heat throughout foods, advances in process engineering coupled with packaging technologies allowed maximum heat penetration and reduction of nutrient losses (CATAURO; PERCHONOK, 2012).

Among the developments, stands out food process optimization, which often consists of finding the heating temperature profile and the process time maximizing the final nutrient retention of a conduction-heated canned food while assuring a certain microbiological lethality (SENDÍN; ALONSO; BANGA, 2010). The microbial lethality of the conventional sterilization was densely reviewed by Li and Farid (2016), plus is well described and published elsewhere.

Overall, the products subjected to be sterilized are disposed in racks inside of a retort equipment, where are exposed to heat by water, air or moisture (AWUAH; RAMASWAMY; ECONOMIDES, 2007). Inside the product the temperatures varies between 100°C to 134°C (BOCA et al., 2002), being more common setting 121°C during process (DROTZ, 2012; TRIBUZI et al., 2015).

Two main heat transfer mechanisms in autoclaving are considered: conduction and convection. The first relates as the heat transferred from one particle to another in straight lines, as
seen in solid or immovable products. The latter is when certain parts of food moves due to density changes, leading to circulation inside the product and assisting to mobilize heat (DROTZ, 2012).

Although there has been concern about environmentally friendly technologies that requires less energy (NELSEN et al., 2009), processing advances on retort like dual mode retorts, retort automation and control upgrades can reduce cost and conserve energy and water (JACOB, 2017).

2.2 USE OF RETORT ON MEAT PRODUCTS

Retort processing has been used for several types of meat products and already has shown its potential to produce safe and nutritious foods. Devadason et al. (2010) combined different starches with buffalo meat to obtain nuggets by retort processing and found notes between 6.3 and 7.4 of appearance, flavor, juiciness and texture in an 8-point hedonic scale. The result of thermal sterilization helped form a dense system in the protein matrix created by the gelatin of salt, soluble proteins through cooking.

Retorted short-rib patties had the niacin content and overall preference increased with low processing times, while the curry flavor and chewiness was higher as higher the sterilization temperature (~121°C) and shorter processing time. When samples were treated for ~19 min., their preference scores were affected only minimally by sterilization temperature; on the other hand, the overall acceptability of samples under longer treatment times (~27 min.) increased with decreasing heating temperature (~119°C) (CHOI; CHEIGH; CHUNG, 2013).

Cheon et al. (2015) reported that retorted meatballs became less harder when processing time and sterilization temperature was decreased. This change in hardness was due mainly to heat treatment that caused conversion of collagen to gelatin and dissociation of muscle protein.

Palka and Daun (1999) observed that at the range of 80-121°C, retorting of Semitendinosus muscle had gradual compression of meat structure on the transverse sections, this was probably connected with gelatinization and loss of intramuscular (mainly perimysium) collagen. A drastic decrease in soluble collagen was noted when samples were heated at 100-121°C, when collagen content in raw samples had 10% whereas cooked had about 4%.

Rajan et al. (2014) with Chettinad chicken, Devadason et al. (2010) in buffalo meat block and Rajkumar et al. (2010) in Chettinad goat meat that were all retort processed, observed a decrease in pH levels along storage period. This might be due to degradation of proteins and liberation of free amino acids.

Rancidity levels, detected as thiobarbituric acid (TBA) values, also increased with storage in the work of Rajan et al. (2014), which brings the necessity to adopt vacuum package or additives in these types of meat products to avoid lipid oxidation.
Over the last years, works with retort processing has moved attention for seafood products. Bindu et al. (2007) evaluated retorted black clam and had flavour score decreased from 8.5 to 6.5 in a 10-point hedonic scale. Even though, after a storage period of 12 months at room temperature, the authors sustained that black clam could be retorted and remained in good condition in both biochemical and sensory aspect.

The retort treatment was also considered a suitable alternative to chopped mussel, preventing spoilage and viable non-refrigerated storage, thus allowing the diffusion of this product in regions where it is not distributed (TRIBUZI et al., 2015). Thermal sterilization reduced the microbial load of fish soup samples inoculated with approximately 10^8 cells/ml Listeria innocua, where no bacteria was detected on TSA-YE plates after 11.5, 6.8 and 5.5 min processing in agitating mode (retort with movables parts inside and thus distributes heat better); 77, 67 and 52 min processing in static mode (static retorts) at 62, 65 and 68 °C respectively (ATES et al., 2014). Additionally, retorted salmon had good acceptance accordingly to pouch material used, reaching up to 12 weeks of storage period when aluminum or silicon oxide were used (BYUN et al., 2010).

Previous research demonstrated that retort processing can at the same time, improve some attributes and reduce others. It may lead to significant product quality losses if not operated properly, as nutrients or sensory parameters (color or texture for instance) can be adversely affected by retort processing. To counterbalance these effects, process optimization using mathematical model models are available to reduce costs and increase process efficiency, maximizing the microbial inactivation, sensory aspect with minimum heat exposure (ALONSO et al., 2013; CHEON et al., 2015).

2.3 HIGH PRESSURE PROCESSING (HPP)

HPP has been increasing its value market since recent progress in equipment design has enabled the development and industrial scale-up transfer and ensured worldwide recognition of the potential for such a technology in food processing, independent of food geometry and equipment size (GEORGET et al., 2015; TORRES; VELAZQUEZ, 2005).

Usually the HPP has been applied in the food industry as a post-packaging pasteurization step to inactivate vegetative microorganisms (GEORGET et al., 2015). Extended research has proven the sterilization capacity of HPP (GEORGET et al., 2015; HUGAS; GARRIGA; MONFORT, 2002; KOUTCHMA; KOUTCHMA, 2014; MÚJICA-PAZ et al., 2011).

Overall, increasingly health-conscious consumers are demanding better food quality, such as improved food safety, nutritional value, freshness and flavors (HUANG et al., 2017). HPP are favored by these qualities since consumers require more environmental friendliness and more natural goods
Such as the clean label foods, which requires free chemical additives, simple ingredients and minimally processed products (HUANG et al., 2017).

Although this technology is effective and readily available, in many cases it has undesirable effects on food quality that a food processor must understand to minimize (TORRES; VELAZQUEZ, 2005). Low-acid HPP products has potential microbial risks associated with survival of Clostridium spores. This technology is not applicable to several food types, such as flour and powdery flavors with low water content or products containing a large number of air bubbles because HPP requires the use of water as a pressure transfer medium and products containing air bubbles will be deformed under pressure. Also, the packaging material used in HPP must have a compressibility of at least 15%, so only plastic packaging materials are suitable for HPP (HUANG et al., 2017).

The HPP equipment consists of pressure vessels where the high hydrostatic pressure comes from pumps or pressure intensifiers (Rahman, 1998). After packing, the product enters a vessel, which is sealed and then filled with a pressure-transmitting fluid (normally water) and pressurized by the use of a high-pressure pump (an intensifier) (Fig. 1). The packages of food, surrounded by the pressure-transmitting fluid, are subjected to the same pressure as that which exists in the vessel itself. After the product has been held for the desired process time at the target pressure, releasing the pressure-transmitting fluid decompresses the vessel (KOUTCHMA; KOUTCHMA, 2014).

For most applications, products are held for 3-5 min at 600 MPa that allows approximately 6-8 cycles per hour including time for compression, holding, decompression, loading, and unloading. Slightly higher cycle rates may be possible using fully automated loading and unloading systems, more powerful pumps, higher throughput intensifiers and/or more pumps and intensifiers. After HPP treatment, the processed product is removed from the vessel and stored or distributed in the conventional manner (KOUTCHMA; KOUTCHMA, 2014).

The pasteurization effect of HPP is not affected by the packaging form and volume of the food, and thus foods of different volumes can be processed in the same batch. Commercial batch vessels have internal volumes ranging from 35 to ~600 L (KOUTCHMA; KOUTCHMA, 2014);
Avure and Hiperbaric, which have gained most of the market share, developed HPP devices with a volume of 525 L and an annual production capacity of approximately 60 million tons (Balasubramaniam et al. 2008).

The effect of HPP on food chemistry is governed by Le Chatelier’s principle, which states that when a system at equilibrium is disturbed, the system then responds in a way that tends to minimize the disturbance. This means that some phenomena as chemical reactivity, molecular configuration and others are accompanied by a decrease in volume, but opposes reactions that involve an increase in volume (Norton; Sun, 2008).

HPP provides sterilization by cellular disruption, which is specific to the geometry of the bacteria to its gram-type (Norton; Sun, 2008). Several studies found five decimal reduction in Salmonella typhimurium, Salmonella enteritidis, Staphylococcus aureus and Vibrio parahaemolyticus, (Reineke et al., 2013; Torres; Velazquez, 2005). Listeria monocytogenes reduction of 5 to 6 log CFU/g in cheese were observed with working pressure of 600 MPa varying between 1, 3, 5 and 10 minutes at 10 °C (Alves; Perez, 2020). The results demonstrated an. Therefore, the HPP inactivation proves to be useful but must be delimited in some aspects, due to limited knowledge regarding the inactivation mechanisms of high resistant bacterial spores (Reineke et al., 2013; Torres; Velazquez, 2005).

Pressure between 300 to 800 MPa at ambient temperatures can lead to unfolding and denaturation of important cell enzymes and proteins in vegetative microorganisms, but the specific pressure effects on microorganism are more complex and have several different mechanisms (Georget et al., 2015).

2.4 TRENDS AND FUTURE MARKET OF HPP

The biggest obstacle for HPP systems is the initial capital investment required, which currently limits its application to high-value products (Norton; Sun, 2008). Cost analysis from Sampedro et al. (2014) concluded that total HPP cost was 7-folds higher than that of conventional thermal processing for orange juice. Since HPP equipment requires a great amount of investment, processing of seasonal commodities demands identifying a product mix achieving maximum utilization of the equipment investment (Torres; Velazquez, 2005). According to Huang et al. (2017), there are more than 300 sets of HPP equipment operating for mass production worldwide, distributed mainly in North America (54%), Europe (25%) and Asia (12%) (Fig. 2); each set of HPP equipment costs approximately $0.5-2.5 million depending on the capacity and operating parameters. (Balasubramaniam; Barbosa-Cánovas; Lelieveld, 2016) states that cost range of HPP is from 0.6 to 4 million USD, distributed in high-pressure vessel, closures, and yoke.
Even though the HPP products has an estimated market value of 355 million USD (KOUTCHMA; KOUTCHMA, 2014). The growing market of HPP in cooked meat and ready meals sectors suggests that the initial investment costs may be sustainable (NORTON; SUN, 2008). However, lack of information of this new technology could lead skepticism of consumers on body health effects and if they will be more costly. This shows that providing consumers with more information about the technologies seems to be a key to achieve consumer acceptance of products manufactured by means of these new technologies (NIELSEN et al., 2009).

Figure 2. World growth of the food industry use of high pressure processing technology

![World growth of the food industry use of high pressure processing technology](source)

Many foodstuffs, like meat products, fruits and vegetables, seafood etc. have already a established market (AVURE Inc., 2017). Suppliers of industrial pressure processing units include Avure Technologies Inc. (www.avure.com/food), Elmhurst Research, Inc. (www.elmhurstresearch.com), NC Hyperbaric (www.nchyperbaric.com) and Uhde GmbH (www.uhde-hpt.com) (MÚJICA-PAZ et al., 2011).

By the end of 2010, about 160 industrial HPP processing units had been installed all over the world with an annual production capacity approaching 250,000 tons. Capital and operating costs will depend of plant operation schedule; pressure come up time (multiple pressure intensifiers reduce the cost); pressure holding time; vessel filing ratio (which depends of the packaging and product, but usually is set to minimum 50%); automation and equipment downtime (personnel training, maintenance etc.) (MÚJICA-PAZ et al., 2011).
2.5 ADVANTAGES AND DISADVANTAGES OF HPP ON MEAT AND MEAT PRODUCTS PROCESSING

In the course of time, consumer’s demands are continuously changing, but some main parameters tend persist: consumers demand high quality and convenient meat products, with natural flavour and taste and very much appreciate the fresh appearance, while providing safe and additives-free products (HUGAS; GARRIGA; MONFORT, 2002).

High pressure could tenderize meat when applied pre-rigor, but studies shown that the contractile myofibrillar proteins are thought to be primarily responsible for the change in textures properties, as collagen is stabilized by hydrogen bound and is little affected by pressure. On the other hand, thermal processing has better outcome on meat texture (MA; LEDWARD, 2004). Even though temperatures at HPP usually rises no more than 20°C (if outside heat is not applied) (NORTON; SUN, 2008), application of high pressure increases the temperature of the food liquid by approximately 3°C per 100 MPa but cool down to their original temperature during the holding stage (RASTOGI et al., 2007). Therefore, both heat and high pressure treatments could be used to improve meat protein functionalities (JIMÉNEZ COLMENERO et al., 1998).

The effects of HPP on proteins are mainly related to the rupture of non-covalent interactions by depolymerisation within protein molecules. Specific pressures have been shown to solubilize myosin and actin and to beneficial effects of pressure on gelation and binding (SIKES; TOBIN; TUME, 2009). Pressures up to 300 MPa are sufficient to promote muscle proteins (including myofibrillar proteins) unfolding. Pressure above this level results in increase on denaturation, gel formation and protein agglomeration (SUN; HOLLEY, 2010).

Besides unfolding, the application of pressure induces subsequent folding after pressure release (BAJOVIC; BOLUMAR; HEINZ, 2012). Even if pressurized, proteins retain most of their secondary structure, and the unfolding exposes hydrophobic regions of the protein, which could lead to protein aggregation (Cheftel and Culioli 1997). HPP prompts breakdown of quaternary structure, whereas tertiary structure changes are observed above 200 MPa and only at 700 MPa or higher secondary structure are affected (RASTOGI et al., 2007).

Because of the protein denaturation and consequently texture and color modification from HPP on meat, most consumers would possibly not recognize as fresh meat (RASTOGI et al., 2007). Sensory evaluation of uninoculated pork grilled patties showed that panellists could not distinguish between those treated by heat and HPP and untreated controls (MURANO et al., 1999).

Nonetheless, pressurized sliced dry-cured ham samples were harder, less juicy, less doughy and more difficult to chew than non-pressurized samples. These textural changes could have been
influenced as a result of oxidative reactions and the partial denaturation of muscle proteins and their modification (FUENTES et al., 2010).

Denaturation of proteins caused by HPP and/or heat lead to lower solubilisation of sarcoplasmatic proteins in meat due to protein aggregation, but for myofibrillar protein, this effect was lower or not observed by Marcos and Mullen (2014) and Sikes et al. (2010). Even though HPP and heat tend to strengthen the myofibrillar fraction of meat, Sikes et al. (2010) suggested that a brittle myofibrillar network was created and, in turn, when exposed to deformation forces, fractures occurred due to crack propagation, leading to improvement in tenderness.

The synergistic reaction of salt on myofibrillar solubility and breakage salt bonds effect of HPP Bajovic et al. (2012) has shown enhancements on meat products. At temperatures of 70°C and 200 MPa, ready-to-eat salted (pickled) duck meat showed reduced cooking loss, hardness and gumminess (KHAN et al., 2014) as well as addition of 1.5-2.5% NaCl on white chicken meat processed at 50-300 MPa, which had higher cohesiveness, gumminess and chewiness (ROS-POLSKI et al., 2015).

The color of meat products were affected by HPP in fresh beef muscle (longissium thoracis et lumborum) pressurised with significant increase of lightness and yelowness, with the highest value observed for 400 and 600 MPa. However, HPP did not alter the redness. The whitening effect caused by HPP has been related to protein coagulation, which would affect the surface properties, and to denaturation of myoglobin with release of heme group (MARCOS; MULLEN, 2014).

Studies that observed an increase in yellowness or decrease in redness explained that this effect could be due to formation of short-lived ferrohemochromyoglobin specie which is transformed into a brown, ferric form of the pigment within the first day of storage (BAJOVIC; BOLUMAR; HEINZ, 2012). This effect on color could be less observed for processed meat products. Work of Andrés et al. (2005) showed that loss of red color on dry-cured ham occurred until 3 days of storage and was subsequently stabilized so that a final redness value was reached comparable to the values measured after 1 day of storage.

The effect on lipid are also seen on HPP, although it has little effect below 300 MPa, this reaction increases proportionally at higher pressures. In fact, treatments between 300 and 400 MPa appears to be critical for inducing marked changes in meat (FUENTES et al., 2010). After treatment at pressures between 300 and 800 MPa, the TBARS content increased in chicken kept at 5°C for 14 days, particularly when the treatment was at more than 400 MPa (ORLIEN, 2009). Similar observations were made for beef pressurized between 200 and 600 MPa for 20 minutes and kept refrigerated for 7 days (MA et al., 2007) 2007).
In general, the effect of HPP on lipid oxidation are linked to meat origin (higher or lower polyunsaturated fatty acids), release of iron of myoglobin and membrane disruption, but these mechanisms are not well understood (BAJOVIC; BOLUMAR; HEINZ, 2012; MATHIAS et al., 2010).

The extent of lipid oxidation depends on the treatment duration, the temperature of the HPP treatment, and mainly on the type of meat or meat product (BOLUMAR; SKIBSTED; ORLIEN, 2012). Beef samples seem to oxidize less than samples of other types of meat and contain, for example, five times fewer volatile compounds than chicken meat (Schindler et al. 2010). In addition, vacuum packaging, which is most frequently used for HPP treatment, reduces the impact of the pressure on the oxidation process (MARIUTTI et al., 2008).

Nonetheless, there are still room for discussion concerning HPP increase or not lipid oxidation. Pressurized turkey meat to 400 MPa had no statistical difference in lipid oxidation when compared to control samples until 30 days of storage at 8°C (MATHIAS et al., 2010). In minced pork, a critical pressure between 300 and 400 MPa was required before a significant increase in lipid oxidation was detected (Cheah and Ledward 1997). Similarly, a significant increase in the TBARS content occurred in chicken muscle after treatment at 500 MPa (Beltran et al. 2004).

HPP leads to radical formation (GUYON; MEYNIER; DE LAMBALLERIE, 2016). Bolumar et al. (2012) studied chicken meat slurries and found that at temperatures of 5, 25, and 40°C no radical formation took place at pressures below 400 MPa. At 400 MPa radicals started to establish at 25°C at rather low amount and at higher amount at 40 °C, whereas at 5 °C radicals started to appear at 500 MPa. Pressure-processed chicken breast and thigh had higher rates of oxygen consumption and tendency of free radical formation (BRAGAGNOLO; DANIELSEN; SKIBSTED, 2007). Nonetheless, addition of free radical scavenger like EDTA, rosemary extract and others antioxidants are helpful as they reduce free radical development in early events in lipid oxidation (MARIUTTI et al., 2008).

3 CONCLUSION

Novel technologies like HPP can serve as an alternative to issues found in retort processing that could reduce consumer acceptance. However, each one has its own advantages; while retort cooks, favors odor and Maillard formation, HPP reduces the oxidation reactions that are increased with thermal treatment; even though lipid oxidation occurs in both retort and HPP processing. A meat producer should consider the application of these equipments and which food product will benefit more of these technologies.
CONFLICT OF INTEREST

The authors declare no conflict of interest.

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