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Review

Effect of high pressure on fish meat quality – A review

Fabiano Alves de Oliveira [a, *], Otávio Cabral Neto [b], Lígia Marcondes Rodrigues dos Santos [c], Elisa Helena Rocha Ferreira [d], Amauri Rosenthal [e]

[a] Food Technology Department Federal Rural University of Rio de Janeiro, UFRRJ and Federal Center for Technological Education, Cefet / RJ, Rio de Janeiro, 23.890-000, Brazil
[b] Federal Institute of Education, Science and Technology of Tocantins, Dianápolis, Tocantins 77.300-000, Brazil
[c] Federal Center for Technological Education, Cefet / RJ, Valença, Rio de Janeiro 27.760-000, Brazil
[d] Food Technology Department Federal Rural University of Rio de Janeiro, Seropédica, Rio de Janeiro, 23.890-000, Brazil
[e] Embrapa Food Technology, Rio de Janeiro 23.020-470, Brazil

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A B S T R A C T

Background: High pressure (HP) is an effective technology in food preservation. However, in fish, changes in appearance, texture, and chemical composition of the meat can be observed in more severe conditions. Although there are proposed mechanisms to achieve these events, there is no consistency of information to conclude on all of them.
Scope and approach: After a brief overview of HP technology, their main impact of fish meat quality were reviewed considering the targeted constituents and underlying mechanisms.
Key findings and conclusions: The main changes occurred between 200 and 300 MPa leading to a partial or total denaturation of proteins. In turn, these modifications were related to the increase of pH, hardness, whitening, decrease in water holding capacity, initiation of lipids, and proteins oxidation. The proposed mechanisms for these effects are very similar, suggesting the interrelationship between them. Lipid oxidation, protein oxidation, and discoloration are enhanced by iron content of the tissues (heme or free) and, possibly, with synergic phenomena. However, there is no consistency of information on the effects of these changes on consumers' opinion. Additionally, the intensity of the changes varies according to type of fish. Research is needed to determine clearly the reaction mechanisms, evaluate the effects of these changes concerning consumers' opinion, and propose devices or strategies to minimize these changes when necessary.

1. Introduction

Consumers increasingly seek food that is safe for consumption, with a long shelf life, easy to prepare and consume, additive–free, and with preserved freshness, sensory, and nutritional properties. However, the production of this type of food requires changes in formulations and processes, which may increase the risks associated with its consumption. In this scenario, physical processes, such as dense phase carbon dioxide, pulsed electric field, ozone processing, ultrasound processing, high hydrostatic pressure processing, radiation processing, high-voltage arc discharge, pulsed visible light, and magnetic fields have gained prominence, since they can extend the shelf life of the product, and promote safety without significant changes in the sensory attributes and nutritional quality (Ma, Ledward, Zamri, Frazier, & Zhou, 2007; Rawson et al., 2011).

High pressure (HP) is a non-thermal technology capable of inactivating vegetative cells of pathogenic and spoilage microorganisms, modifying enzymatic activity, reducing losses of desirable compounds, thus preserving freshness and nutritional values of foods (Huang, Lung, Yang, & Wang, 2014). Its application in fish and fish products is based on the ability to render inactivate parasites and microorganisms, to increase shelf life, and provide increased performance of the deboning process of bivalves and crustaceans, promoting easier and complete removal of meat.

Fish has high nutritional value, especially high biological value proteins and lipids, being marketed and consumed worldwide. Fatty fish has high concentration of n-3 fatty acids, which is often perceived by consumers as beneficial for human health (Ruxton, Calder, Reed, & Simpson, 2005). However, fish is highly perishable due to their pH which is close to neutral, presents high water

* Corresponding author.
E-mail address: fabiano.oliveira@cefet-rj.br (F.A. Oliveira).

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activity, is rich not only in unsaturated fatty acids but also in free amino acids, and exhibits active autolytic enzymes, making it prone to microbial and oxidative degradation (Lougovois & Kyrana, 2005). Moreover, it is often eaten raw or undercooked, serving as vehicles for many health hazards. Among the conventional preservation methods, heat treatment can lead to changes in appearance, texture, and flavor, besides affecting nutritional value. In turn, refrigeration can slow its deterioration rate, but limits shelf life to 7–14 days (Chaijan, Benjakul, Visessanguan, & Faustman, 2006; Pereira & Tenuta-Filho, 2005), while freezing extends shelf life, but can lead to undesirable changes in nutritional value, such as cholesterol oxidation (Saldanha, Benassi, & Bragagnolo, 2008), besides incurring high energy costs in processing and storage.

HP assessment in fish has been intensively carried out since the 1990s, with very positive results. As for other preservation processes, the benefits strongly depend on the intensity and time of the HP treatment. There is consensus that applied pressure between 500 and 600 MPa can be effective for stabilization of meat, providing pasteurization conditions (Campus, 2010; Guyon, Meynier, & Lamballerie, 2016). However, effects such as discoloration, increased hardness, changes in water holding capacity, pH variations, lipid oxidation, protein oxidation among others, can occur in more intensive treatments. Thus, it is essential to understand the mechanisms of these changes, to propose alternatives to minimize their negative effects. The objective of this research is to address the effects of HP on the physicochemical characteristics of fish, and further discuss underlying mechanisms.

2. Overview of HP technology

HP studies were initially reported in 1899 for milk conservation, and rose to industrial scale in 1990 in Japan, in the processing of jams, jellies, and sauces, and later in the USA, in guacamole (Rastogi, 2013). In 2010, there were about 150 high pressure units worldwide, processing 250,000 tons of vegetables (33%), meat (30%), fish (15%), and juices and beverages (12%), comprising 71 industries in America, 26 in Europe, 22 in Asia, and 5 in Oceania (Campus, 2010; Mújica-Paz, Valdez-Fragoso, Samson, Welti-Chanes, & Torres, 2011). Over the past seven years, industrial equipment reached more than 300 units worldwide, mainly located in North America (54%), Europe (25%), and Asia (12%), moving $ 10 billion in 2015, with a tendency to increase and to reach $ 54.7 billion in 2025 (Huang, Lung et al., 2014; Huang, Wu, Lu, Shyu, & Wang, 2017; Pérez, 2015).

The HP system consists of a pressure chamber, a generation and intensification pressure systems, and a compression fluid (usually water or alcoholic solution). During operation, the compression fluid which increases the pressure is forced into the chamber containing the sample. The industrial food processing equipment is around 500 L capacity, capable of operating at maximum pressures of 900–1200 MPa, although the most common is around 400–600 MPa (Bajovic, Bolumar, & Heinz, 2012; Balasubramaniam, Farkas, & Turek, 2008). Usually, most of the pressurized samples are already packaged in flexible plastic material prior to the high pressure processing.

Although the equipment is expensive, ranging from $ 500,000 to $ 2.5 million, the operating costs are in the same order of magnitude than other thermal processes (Balasubramaniam et al., 2008; Campus et al., 2010), ranging from $0.05 to 0.5/L (or Kg)., (Mújica-Paz et al., 2011; Rastogi, 2013). However, it is possible that consumers will be willing to pay $ 0.25–0.50 more for pressurized products ready for consumption (Hicks et al., 2009).

The worldwide spread of technology involves the development of different applications. Initially, the pressurization was conducted with the main objective to promote conservation and food safety (by inactivating microorganisms or modifying enzymatic activity). HP is also able to promote changes in the rheological properties of biopolymers, acting as assistant thawing, enabling reduction in salt content and allergenic potential of foods, and as a preprocess for the extraction of bioactive compounds (Balasubramaniam et al., 2008; Barba, Shiferaw, Buckow, Knorr, & Orlien, 2015).

The various applications of HP are due to the fact that it is a selective technology with main direct effects on macromolecules such as proteins, enzymes, lipids, and carbohydrates, and water molecules, while the compounds with low molecular weight commonly associated with the sensory and nutritional quality (vitamins, minerals, aromatics, flavors, etc.) are not affected by HP treatment (Huang, Hsu, Yang, & Wang, 2014). This is because the chemical interactions that stabilize these compounds behave differently when subjected to HP, and while covalent bonds are not affected by the process, other interactions (ionic interactions, hydrophobic, hydrogen bonds, disulfide bonds) may be more easily affected.

The effects of HP on food components are the result of related thermodynamic principles. The pressure is transferred uniformly and instantaneously to the entire sample (***Isostatic Principle***) independent of its size, shape, or rheology, without gradient inside the equipment, between the equipment and the sample, and between different locations in the sample (Barba et al., 2015; Campus, 2010; Truong, Buckow, Stathopoulos, & Nguyen, 2015). Hence, in order to minimize the pressure effect (***Le Chatelier Principle***), reactions that have a final volume smaller than the initial volume ($\Delta V<0$), such as protein compaction, fat solidification, reorganization of water molecules into smaller volume arrangement, are favored in the sample (Bajovic et al., 2012; Cheftel & Culioli, 1997; Mújica-Paz et al., 2011). However, volume reduction is not enough to completely compensate pressure effect and then temperature raises (***Adiabatic Heat***). Although it is considered a non-thermal technology, slight heating may occur according to pressure levels, food composition, and initial temperature (pure water at 25 °C and 90 °C can increase 3° C/100 MPa, and 5.3 °C/100 MPa, respectively, and high-fat foods can present temperature increases from 6 to 8.7 °C/100 MPa (Balasubramaniam, Ting, Stewart, & Robbins, 2004)), even though after depressurization, the temperature returns to initial values close to, or slightly lower, due to heat losses during the process (Balasubramaniam et al., 2008).

This technology is commonly unable to sterilize products, since a pressure of up to 1700 MPa may be used (Barbosa-Cánovas, Medina-Meza, Candoğan, & Bermúdez-Aguirre, 2014), which is commercially unfeasible due to the high cost and the undesirable effects on a product's quality. An alternative is the association of HP with temperature. Studies have shown an effectiveness of the association between pressure and temperature for sterilization (Ahn, Lee, & Balasubramaniam, 2015; Nguyen, Balasubramaniam, & Ratphitagsanti, 2014) and preservation of physicochemical, sensory, and nutritional quality of foods (Barbosa-Cánovas et al., 2014; Sevenich et al., 2013).

3. Effects of HP on fish meat

The effects of HP on fish have been reported especially for those with higher added value, such as shrimp, salmon, cod, and oysters, among others. The most common treatments use pressure levels between 100 and 600 MPa for a period of time ranging from a few seconds to 10–15 min. Table 1 presents some publications about the application of HP in fish, showing species and pressurization parameters (time, pressure level, and temperature). Considering the similarities of some biochemical and physiological aspects between fish, seafoods and land animals, some HP studies with mollusks, crustaceans, cattle, pigs, and poultry have been included