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MINI REVIEW

The use of ultrasound and slightly acidic electrolyzed water as alternative technologies in the meat industry

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Abstract

The quality of meat from different animal species is defined by chemical, physical sensory and microbiological characteristics, which can be influenced by procedures during the slaughter of animals. Technologies such as ultrasound (US) and slightly acidic electrolyzed water (SAEW) are being studied in order to assist in food processing and in developing methods that are economically viable and environmentally sustainable. The aim of this paper is to discuss the relationship between US and SAEW in relation to tenderness, microbiology, and oxidation of meat. The meat industry was a pioneer in the use of the ultrasound, which initially aimed to determine the layer of fat on carcasses and subsequently improve the tenderness of the meat. Recently studies mention that the ultrasound and SAEW can influence the microbiological parameters. The combination of both technologies should also be considered, with the possibility of enhancing the antimicrobial effects. However, there is little information regarding oxidative parameters promoted in meat for these two alternative technologies, where the individual or when interspersed use. Knowing the actions and consequences of ultrasound and SAEW in meat will enable the opening of new perspectives about the application of these technologies in the meat industry.

1. Introduction

The meat quality of different species of slaughtered animals can be characterized by parameters such as appearance, texture, taste, color, and aroma (Vieira, 1999). Historically, the equipment's modernization and industrial's installations made possible that the meat industry offers a meat with quality and with a satisfactory microbiological safety to the market (Gomide *et al*., 2009). Technological innovations developed for the agro-industrial sector are optimized to enhance value and preserve the quality of food, to protect the environment and to allow the conquest of markets internationally (Santini and Filho, 2003; Sereia *et al.*, 2015).

Alternative technologies, such as slightly acidic electrolyzed water (SAEW) and ultrasound (US), are simple ways of optimizing the use of natural resources, providing economy investment (Clark, 2011) and assisting the preservation of foods (Chemat *et al.*, 2011). The application of US can benefit the meat by modifying the tenderness of it (Jayasorryia *et al*., 2004). When combined with high temperatures, its effect against the bacteria development tends to increase (Pagan *et al*., 1999). Applications of SAEW have shown opposite effect against the bacteria in various temperature ranges and application modes (Northcutt *et al*., 2007; Koide *et al*., 2009). However, the SAEW and US still require greater understanding to enhance its applications and, consequently, be used in the meat industry. Therefore, in this review, will be discussed the principles of these alternative technologies in contact with the tenderness, microbiology and the meat oxidation.

2. Ultrasound

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In the perspective of food technology, US is a sound wave with a high frequency vibration, which promotes a mix of fluids and the shear force (Kentish and Feng, 2014). The sound spectrum can be divided into regions, which are low frequency and high intensity (20-100 kHz) and high frequency and low intensity (1-10 MHz) (Patil *et al*., 2013).

The ultrasound effects are originated from cavitation (Shchukin *et al.*, 2011), which can be considered as small implosions that provide detachment of energy levels. In local operations, the gaseous and liquid phases reach temperatures of about 2000-5000°C and pressures above 1000 atm (Suslick *et al.*, 1986). Cavitation mainly occurs at low frequencies and its energy increases with the rise of the wave's intensity (Got *et al.*, 1999).

2.1 Ultrasound and meat tenderization

In order to add value to the meat and make it tender, techniques are routinely used in cutting with less degree of tenderness and less profitable portions in carcasses with a high-grade finishing (Kinsman *et al*., 1994; Bekhit *et al.,* 2014). Traditional methods are used by the meat processing industry to improve the meat tenderness, including mechanical, enzymatic and chemical forms (Mane and Dhanze, 2014). In laboratory and pilot scale, various US applications have been proposed in the meat processing and beneficiation, such as in the meat tenderization (Zhou *et al*., 2015). The US can act in muscle tissue promoting changes in physical structures and protein and enzymatic metabolism, improving the meat tenderness (Jayasooryia *et al*., 2004). As well as in the changes of proteolysis and water retention capacity (Dolatowski *et al*., 2007) and in the action of the enzyme involved in the meat maturation (Got *et al*., 1999).

Chang and Wong (2012) exposed fish filet to US of 60 kHz, 4W/ cm² of intensity and observed that the firmness of the sonicated files obtained values of 8 to 9 N, compared to 14 to 15 N of the non-sonicated groups. The authors suggested which ultrasound promoted the acceleration of protein and enzymatic metabolism of the fish filet. Xiong *et al*. (2012) applied 25 kHz US, 12 W/ cm² intensity for 4 minutes in chicken breast and observed reduction by 1.19 kg of shear force compared to non-sonicated groups. This reduction is related to an increase in the proteolytic enzyme activities after the ultrasound application, such as caspase-3, which favored muscle degradation, tenderness and water retention of the poultry meat.

2.2 Ultrasound and microbiological contamination of meat

Because of the microbiological contamination risk of the meat during the steps in the process, the slaughterhouses use chlorinated water (Kotula *et al*., 1974; Tozzeti *et al*., 2009; Kameyama *et al*., 2012) to assist in the carcasses decontamination and the cooling to extend the meat shelf life (Cunningham and Lawrence, 1977; Jay, 2005). Considering the high consumption of water in the slaughterhouses, Krieger (2007) suggested a volume reduction of 50% through the implementation of more effective technologies in sanitizing and cleaning processes. Due to the practicality of application, antimicrobial activity, and environmental sustainability, the ultrasound is the target of research and development on a reduced scale in the agro-industrial segment (Chemat *et al*., 2011).

The most probable mechanism of microorganism inactivation by the US would be the direct effects of cavitation and the production of reactive species of oxygen would be the indirect effects. In sonication of aqueous solutions, occur the formation of hydroxyl radicals (•OH), hydroperoxide (•OOH) and extremely reactive species of hydrogen (•H) (Suslick, 1989; Mason and Lorimer, 2002), which can recombine to the form of peroxide hydrogen (H_2O_2) (Hua and Thompson, 2000). According to Hua and Thompson (2000), these oxidizing species can diffuse and strike organic structures, functioning as sanitizers.

The low frequency and high intensity of US reduced by1 to 2 log CFU/cm² enterobacteria, such as *Salmonella enterica* serovar Derby and Infantis*, Yersinia enterocolitica* and *Escherichia coli,* which are present on the surface of carcasses and meat pork when they were combined by pressure for 4 to 10 seconds (Morild *et al*., 2011). A number of mesophilic aerobic and lactic acid bacteria present in meat pork, decreased 40 to 50% after 2 minutes with the 25 kHz US and 2W/cm² intensity (Dolatawski and Stasiak, 2002). As was also observed reduction by 3 log CFU/cm² enterobacteria, mesophilic aerobic and psychrotrophic bacteria in beef exposed with 40 kHz US and 11 W/cm² intensity for between 60-90 minutes (Caraveo *et al*., 2014).

The antimicrobial action of the US is favored in temperatures between 60°C and 70°C (Raso *et al*., 1998; Pagan *et al*., 1999; Cichoski *et al*., 2015), because these temperatures make the microorganism's cell structure more susceptible to the physical actions, favoring the sonication effects. Even that, the antimicrobial effect of the US is more efficient at higher temperatures, Alliger (1975); Guerrero *et al*. (2001) and Herceg *et al*. (2012) reported that in temperatures between 10°C and 20°C, the environmental conditions make the cavitation potential more intense, which further favor the formation of reactive oxygen species (ROS) and shear strength.

3. Electrolyzed water

In order to be generated in a traditional manner, the chlorinated water needs to pass through the manipulation of large volume of highly volatile chemicals, which are irritants to the respiratory tract and harmful to human health (Brazil, 2004). However, the use of new technologies for the generation of chlorinated water, such as electrolysis, can make this process more practical, simple and environmentally appropriate (Rahman *et al*., 2016). Due to its minimal corrosive potential, SAEW may be less aggressive to human health and the environment, requiring minimum safety processes to manipulate it (Zacharia *et al*., 2010). The operational costs associated with the application of SAEW can also be lesser because of the possibility of local production (Al-Haq *et al*., 2005).

The operation's principle of the electrolyzed water equipment consists of the passage of a saline solution (NaCl or KCl) in pure water through an electrolysis cell, which is composed of two poles: positive (anode) and negative (cathode) (Zoulias *et al*., 2013). The saline solution generates an electric current between the poles, and the changes in its concentration may generate different chlorine values available. With variations from 2 to 20 g/L of NaCl in pure water, it is possible to produce electrolyzed water with chlorine concentrations from 5 to 200 mg/L (Hsu, 2005; Rahman *et al*., 2016). The mixture of acidic electrolyzed water and basic electrolyzed water forms the SAEW, which has a pH between 6 and 6.5, oxidation-reduction potential (Eh) 800-900mV, containing predominantly HOCl (95%) and hypochlorite ions (ClO^- – 5%) and traces of Cl_2 (Guentzel *et al*., 2008).

3.1 Slightly acidic electrolyzed water and microbiological contamination of meat

The SAEW includes mechanisms that promote the reduction of microbial growth and the inactivation of microorganisms. These mechanisms occur through oxidation of protein compounds involved in cellular metabolism, cellular rearrangements, induction of DNA damage (Huang *et al*., 2008), apoptosis and redox reactions involving electron transfer and formation of disulfide bridges (Liao *et al*., 2006).

The SAEW has aroused great interest in agriculture, medicine and the food industry for its versatility, showing the antimicrobial activity even when it is applied in different ways. Studies have demonstrated with SAEW in chlorine concentrations between 5 and 120 mg/L, were effective to reduce by5 to 6 log CFU/cm² *Escherichia coli*, *Listeria monocytogenes*, *Staphylococcus aureus* and *Salmonella enterica* serovar Enteritidis in fresh meat of chicken, beef and pork (Ayebah and Hung, 2005; Northcutt *et al.*, 2007; Koide *et al*., 2009; Zhang *et al*., 2011; Shimamura *et al*., 2015). In addition, it was effective in the cleaning and disinfection of knives and food processing equipment (Fabrizio and Cutter, 2005; Huang *et al*., 2008; Cao *et al*., 2009; Cichoski *et al*., 2015).

Most of the SAEW applications in food was performed at temperatures between 20°C to 40°C (Kim *et al*., 2005; Ding *et al*., 2015; Shiroodi *et al*., 2016). However, Cao *et al*. (2009) and Rahman *et al*. (2013) observed that SAEW retained its antimicrobial activity even when it is applied at temperatures between 5°C and 10°C because it reduced 3 log CFU/cm² *Listeria* spp., *Escherichia coli,* and *Salmonella* spp., inoculated on the surface of eggs and pork.

The SAEW combined with other alternative technologies can potentiate its antimicrobial effects, further assisting in reducing the number of microorganisms (Liu *et al*., 2013). Recently, the combination of US and SAEW technologies has been described with satisfactory results. In the same way, Forghani and Oh (2013) and Ding *et al*. (2015) which associated US of 40 kHz with SAEW (25-30 mg/L Cl_2 at 25°C) observed an increase of 20% to 30% reduction of the number of microorganisms, as compared to isolated application of technology. It shows that synergism occurred between technologies because the cavitation effects facilitated the penetration of chlorinated compounds of SAEW in the microorganisms' cellular structure.

4. Ultrasound and slightly acidic electrolyzed water effects in meat oxidation

There is little information on the effects of US and SAEW lipid and protein oxidation, restricting the studies of specific species of meat. This information becomes important because the sonication of water can generate ROS, pressures and high temperatures (Marchioni *et al*., 2009) and SAEW can also cause damage to biological

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structures, including the muscle tissues (Shirahata *et al*., 1997).

Fish filets, which were exposed for more than 30 minutes in US of 60 kHz and 4W/mL of intensity, present strongly indicative of increased muscle metabolism and proteolysis during the storage period, which contributed to increase by 0.01 to 0.2 mg/MDA/kg the value of thiobarbituric acid reactive substances (TBARS) (Chang and Wong, 2012). Turienzo *et al*. (2012) demonstrated that the application of 35 kHz US to fresh salmon for between 15 and 20 minutes, showed low values of lipid oxidation (6 meq/kg peroxides and 1.25 mg/MDA/kg TBARS). In non-sonicated fresh salmon, showed 9 meq/kg peroxides and 6.5 mg/MDA/kg TBARS. These values of low lipid oxidationwere correlated to the changes occurred in the fish filets protein structure and, consequently, it protected that compounds would suffer deterioration.

Apparently, the SAEW application in fish and pork showed reduction and no interference in the formation of oxidized lipid compounds. Rahman *et al*. (2013) reported that pork immersed for 10 minutes in SAEW at 25°C with pH 6.8, Eh of 700mV and chlorine concentration of 10 mg/L showed no changes in the formation of TBARS compared to control treatments with distilled water. Mahmoud *et al*. (2006) reported that the immersion of carp filets in basic electrolyzed water (pH 11, Eh -850 mV and 0 mg/L Cl_2) at first and then in acidic electrolyzed water (pH 2, Eh 1137mV and 40 mg/L Cl_2) at 25°C for 15 minutes, significantly reduced by 3 to 4 meq/kg the amount of peroxides compared to untreated groups. The immersion in basic water could function as an antioxidant, preserving tissues and oxidative damage structures (Shirahata *et al*., 1997).

Oxidative and functional mechanisms of meat protein are briefly studied following US applications, but they are not described in the SAEW application. Low frequency and high intensity of US can react to decrease the size of particles in bovine protein extracts, fish and bovine serum albumin (Gülseren *et al*., 2007; Sullivan *et al*., 2016). Gülseren *et al*. (2007) also reported that free thiol groups were reduced 30% after the application of ultrasound in bovine serum albumin extracts, suggesting that ROS produced by sonication can react with albumin and thereby contribute to oxidative changes demonstrated.

5. Conclusion

The US can tenderize cuts of meat by direct and indirect effects of cavitation and can ensure the safety to present the effect of microorganism inactivation. The SAEW has great potential for using in the meat industry due to its antimicrobial effects are maintained when it is used in various forms and application temperatures. The antimicrobial action can be potentiated with the reconciliation of SAEW and US by combining the effects of cavitation and chlorine. Both technologies can reduce the consumption of natural resources and chemicals used by agribusinesses and be as effective as traditional methods or more than this. The oxidative effects of ultrasound are not clear, and there is a tendency to induce lipid and protein oxidation. However, the use of SAEW does not induce oxidative alterations, promoting the use of basic water previously the reduction of oxidative changes. Further studies are needed on the application of these technologies in relation to protein and lipid oxidation in the meat of different species to make the development of large-scale applications possible.

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