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The use of power ultrasound for accelerating the curing of pork

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ABSTRACT

Power ultrasound (10, 25 or 40 min at US intensities of 4.2, 11 or 19 W cm^{-2}) was assessed for accelerating brine transfer into meat. Sample analysis included NaCl content, water content, water-binding capacity, colour and texture. Water content (g/100 g) was increased by 19 W cm^{-2} for 10 or 25 min ($p \leq 0.05$). NaCl content (g/100 g) was increased by all ultrasonic treatments ($p \leq 0.001$). Decreased cohesiveness ($p \leq 0.05$) and gumminess ($p \leq 0.05$) were evident in sonicated samples. Ultrasonic curing can assist brine transfer, reducing processing times with minimal impact on product quality.

1. Introduction

Curing of meat is an ancient preservation technique which involves the addition of salt to reduce the water activity below a tolerable level for spoilage micro-organisms (Feiner, 2006). Evolution of curing techniques has led to a diverse range of products being available globally, which can be classified by curing method (dry or wet-cured) (Pegg, 2004). Wet-curing involves the addition of a brine solution which will commonly contain NaCl, phosphates, nitrates and other functional ingredients (Feiner, 2006). Nitrate is the key curing ingredient through its ability to produce nitrosomyoglobin, the distinctive pink colour pigment of cured meats (Pegg, 2004). However, NaCl is the most important functional ingredient (Feiner, 2006). NaCl alters the meat structure leading to greater water entrapment within the myofibril, thereby enhancing water holding capacity (WHC). This will affect the sensory properties of flavour, juiciness and tenderness (Hamm, 1961).

With all curing methods, NaCl must diffuse into the complex meat matrix (Siró et al., 2009) and this is a slow process. Traditional products cured by immersion in brine can take 2–2.5 days per kg to reach a NaCl level of 1.6–2.2% (Feiner, 2006). Although wet curing can be speeded up by brine injection, excessive injection may cause needle damage (Jayasooriya, Torley, D'Arcy, & Bhandari, 2007) and lead to low quality products. Reduced curing times and improved curing operations may be achieved through vacuum tumbling (Hayes, Kenny, Ward, & Kerry, 2007), thaw-salting (Barat et al., 2006) and high-pressure curing (Villacís, Rastogi, & Balasubramaniam, 2008). The cured meats industry would benefit from new alternative curing techniques that produce high-quality products under accelerated conditions. Moreover, increasing competition and consumer demand are driving industry interest towards new processing technologies to replace old ones (Leal-Ramos, Alarcon-Rojo, Mason, Paniwnyk, & Alarjah, 2011).

Power ultrasound (US) is a novel processing technology which may accelerate mass transfer through the mechanism of cavitation, the implosion of microscopic gas bubbles due to sound-wave pressure fluctuations at frequencies of 16–100 kHz (Jambrak et al., 2010), resulting in extremely high temperatures and pressures in localised areas. Cavitation also leads to micro-stirring and pressure gradients which can increase the velocity of ions within a solution and decrease the magnitude of a boundary layer (Lenart & Ausländer, 1980). Additionally, when a cavity implodes, microjets are created which can penetrate a solid surface leading to enhanced movement of ions (Siró et al., 2009). It has been suggested that water and NaCl transport is accelerated above US intensity thresholds of 64 or 51 W cm^{-2}, respectively (Cárcel, Benedito, Bon, & Mulet, 2007), while others contradict this stating that NaCl diffusion increases exponentially within the US intensity range of 2–4 W cm^{-2} (Siró et al., 2009) or that US does not affect the curing rate (Paulsen, Hagen, & Bauer, 2001). Likewise, studies assessing the benefits of US on meat tenderisation are conflicting. Some studies suggest that US (24–25.6 kHz) will tenderise beef (Jayasooriya et al., 2007; Smith, Cannon, Novakofski, McKeith, & O'Brien, 1991), while others have reported no effect of US on meat texture and the rate of beef (Got et al., 1999; Lyng, Allen, & McKenna, 1998a) or lamb proteolysis (Lyng et al., 1998b).

The problem may be in the reporting of US studies. Inadequate reporting of experimental set-up makes it difficult to replicate an ultrasonic study; therefore the field is slow to evolve (Cárcel et al., 2007; Crum, 1995). US power is affected by the characteristics of the equipment, vessel and medium. For instance, power output

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increases with decreasing temperature and increasing viscosity (Mason, Lorimer, & Bates, 1992; Raso, Mañas, Pagán, & Sala, 1999). Factors such as vessel geometry, dissolved solids, pressure and frequency will also affect power output (Berlan & Mason, 1992; Mason et al., 1992). In addition, all units of the acoustic field should be reported where applicable. Some authors report frequency with power (W) (Dolatowski, 1988; Smith et al., 1991) or ultrasonic intensity (W cm^{-2}) (Cárcel et al., 2007; Siró et al., 2009), while others report amplitude (um) (Tiwari, Patras, Brunton, Cullen, & O'Donnell, 2010) and some report no parameters at all (Reynolds, Anderson, Schmidt, Theno, & Siegel, 1978; Vimini, Kemp, & Fox, 1983).

It is also recommended to quantify the actual power output (Cárcel et al., 2007; Crum, 1995; Kimura et al., 1996) rather than the manufacturer's specification as the efficiency to convert electrical power to mechanical power is dependent on the condition of the transducer and the horn (Kimura et al., 1996). The acoustic field can be characterised by many methods. Several authors have suggested the use of chemical dosimeters with the most common reaction being the Weissler reaction (Kimura et al., 1996). This involves the use of ultrasonic irradiation to liberate iodine from potassium iodide. Although dosimetry is a reliable and repeatable method, it is difficult to find a reaction suitable for all solvents (Kimura et al., 1996). For this reason many authors conducting ultrasonic studies on food systems have chosen calorimetry (conversion of US energy to heat) to measure acoustic power (Cárcel, Benedito, Bon, & Mulet, 2007; Cárcel, Benedito, Rosselló, & Mulet, 2007; Leal-Ramos et al., 2011). By measuring the temperature rise over time of a known mass of liquid, the energy can be calculated (Raso et al., 1999). Calorimetrically measured power has been shown to have a direct linear relationship with the Weissler reaction (Kimura et al., 1996). Furthermore, when Cárcel et al. (2007) compared calorimetry to a hydrophone, the standard deviation of calorimetric measurements remained constant, while the standard deviation of hydrophone measurements increased with power output, presumably being affected by cavitation. Moreover, calorimetry is a method which is feasible for repetition in different laboratories so it has been recommended as a method for measuring the energy output of US probes (Cárcel et al., 2007).

The objective of this study was to assess the efficacy of power US at three intensities (4.2, 11 and 19 W cm^{-2}) and three treatment times (10, 25 and 40 min) in accelerating brine mass transfer into the meat matrix and to assess the effects of these US treatments on meat quality parameters.

2. Materials and methods

2.1. Ultrasonic equipment and calorimetry

An ultrasonic probe (XL2020, Heat Systems Inc., USA) with a maximum power output of 550 W at 20 kHz frequency was used. The emitting surface had a diameter of 12.7 mm. Assuming that almost all of the mechanical energy produces heat at the beginning of sonication, the energy output may be calculated calorimetrically (Kimura et al., 1996). Firstly, calorimetry was performed as described by Lyng (1995) using the same probe as used here to determine if the equipment had degraded with time. This involved sonication of 0.05 kg of water (thermostated at 17–19 °C) in an insulated 100 ml beaker, with 82.5 W for 3 min. Secondly, calorimetry was performed on the experimental apparatus (Fig. 1) to determine the actual intensity achieved. All parameters of the experimental design were kept as shown in Fig. 1 but the coolant was not circulated as this is not required for calorimetry (McDonnell, Allen, Morin, & Lyng, 2013). The amplitude setting was turned to 3.5 (42 μm). At this setting, the LCD display shows 15%. Assuming the ultrasonic system is working to 100% efficiency, this equates to 82.5 W (15% of 550 W). The temperature rise was recorded over a 3 minute period using a data logger (Tiny Tag View 2 TV-4020, Gemini Data Loggers Ltd., UK). The energy (J) was calculated using Eq. (1).

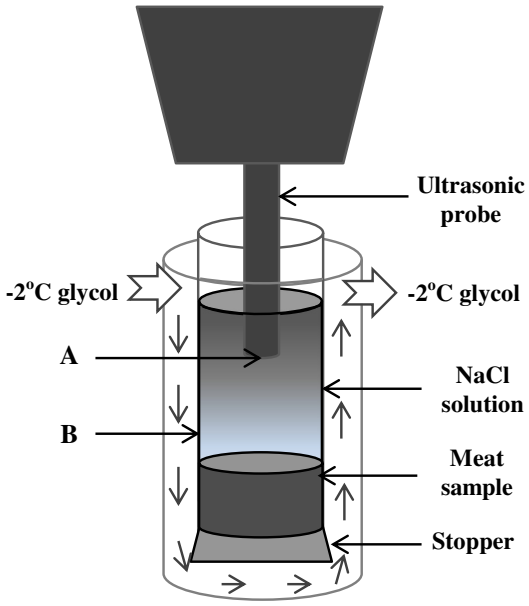

Fig. 1. Experimental treatment vessel for US treatments. Energy losses were calculated at titanium to saline interface (A) and saline to glass interface (B) by entering impedance (Z) values (Table 1) into Eq. (2).

$$\Delta J = m\gamma\left(\frac{dT}{dt}\right) \quad (1)$$

where ΔJ is the quantity of heat gained by the liquid, m is the mass of liquid (kg), γ is the specific heat capacity of the liquid (J kg^{-1} $°C^{-1}$) and dT/dt is the temperature change (°C). The process was repeated 5 times. Heat losses to the surroundings may occur (Yamaguchi, Nomura, Matsuoka, & Koda, 2009); therefore adjustments were made to the calorimetrically measured output by estimation of impedance matching at the interface of interacting materials. When a sound wave travels through junctions, interactions between the wave and the material occur. The wave may be scattered, transmitted and dissipated depending on the properties of the junction. The impedances of the two interacting media determine how much of the wave is transmitted onwards and how much is transmitted back (Fahy, 2003). If two materials have identical impedance their ratio will be 1 and therefore all of the sound energy will pass through the junction; if impedances are greatly mismatched, some energy will be reflected back through the initial medium (Breazeale & McPherson, 2007). The amount of energy reflected can be calculated (Eq. (2)) if the acoustic impedance of the two materials is known. The acoustic impedance (Z) of a material is the product of the density (ρ) multiplied by the speed of sound (c) and the unit is MRayl, where 1 MRayl is equal to 10^6 kg m^{-2} s^{-1} (Jacobsen, 2007).

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \quad (2)$$

where Z_1 and Z_2 are the impedances of the two materials. As the total wave is 100%, the energy transmitted can be calculated as $T = 1 - R$ (Breazeale & McPherson, 2007). Adjustments were made to calorimetrically calculated power output for reflectance losses at the titanium to saline interface and transmission losses at the saline to glass interface, shown as A and B, respectively in Fig. 1. The impedance values of materials are presented in Table 1. The reported ultrasonic intensities of 4.2, 11 and 19 W cm^{-2} (Table 2) correspond to calorimetric as shown in Table 3 and reported by McDonnell et al. (2013).