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Review

Power ultrasound in meat processing

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A B S T R A C T

Ultrasound has a wide range of applications in various agricultural sectors. In food processing, it is considered to be an emerging technology with the potential to speed up processes without damaging the quality of foodstuffs. Here we review the reports on the applications of ultrasound specifically with a view to its use in meat processing. Emphasis is placed on the effects on quality and technological properties such as texture, water retention, colour, curing, marinating, cooking yield, freezing, thawing and microbial inhibition. After the literature review it is concluded that ultrasound is a useful tool for the meat industry as it helps in tenderisation, accelerates maturation and mass transfer, reduces cooking energy, increases shelf life of meat without affecting other quality properties, improves functional properties of emulsified products, eases mould cleaning and improves the sterilisation of equipment surfaces.

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1. Introduction

Ultrasound is an innovative technology that has applications in both the analysis and the modification of foodstuffs and is defined as being sound waves higher than those that can be detected by the human ear (20 kHz). When sound travels through a medium, it generates waves of compression and rarefaction of the particles in the medium (Povey & Mason, 1998) with the result being the formation of cavities and/or bubbles. These cavities grow with subsequent cycles of ultrasound and eventually become unstable and collapse releasing high temperatures and pressures. If this collapse is within a biological material ultrasound can affect these biological materials and tissues on micro- and a macro-scale. In the case of food processing, the effects are in general positive in

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that they can be applied to promote increased food quality and safety. The ranges of sound used are divided into high-frequency, low-intensity ultrasound (>1 MHz, <1 W cm^{-2}) and low-frequency, high-intensity ultrasound (20–100 kHz with 10–1000 W cm^{-2}), also known as power ultrasound. Both types are useful in food technology. The former is non-destructive and is used for analysis or characterization of compounds while the latter can be used to modify cell structures and in a number of other processes such as foam inhibition, emulsification, inhibition or activation of enzymes and crystallization (Mason, Paniwnyk, Chemat, & Abert Vian, 2011; Mason, Paniwnyk, & Lorimer, 1996). In meat processing, power ultrasound can modify cell membranes which can help in curing, marinating, drying and tenderising the tissue. However, these processes need to be developed further before they can be implemented at a full industrial level. The aim of this paper is to review the effects of power ultrasound on the technological properties and quality of meat.

2. Power ultrasound in meat processing

In recent years several studies have reported the effects of power ultrasound on fresh and processed meat. The resulting changes in the physicochemical characteristics, cooking, processed, brining, microbial growth, freezing, cooking and cutting of meat are summarized in Table 1.

2.1. Physicochemical characteristics

Meat quality depends on aroma, taste, appearance, texture and juiciness. Consumer behaviour indicates that texture is the most important palatability factor in determining the quality of meat (Smith, Cannon, Novakofski, McKeith, & O'Brien, 1991). Texture is dependent upon factors such as the tenderness of the meat, its WHC (juiciness) and also the degree of maturation.

2.1.1. Tenderness

Traditional tenderising methods used to make poor-quality meat more palatable include mechanical, enzymatic and chemical approaches. In one of the first publications in this area research on meat sterilisation using heat and ultrasound found tenderising to be a beneficial side effect of this sterilisation process (Pagan, Mañas, Alvarez, & Condon, 1999) however the authors did not report the intensity and frequency of the ultrasound applied. Technically, ultrasound can act in two ways in the meat tissue: by breaking the integrity of the muscle cells and by promoting enzymatic reactions (Boistier-Marquis, Lagsir-Oulahal, & Callard, 1999). While some authors (Jayasooriya, Bhandari, Torley, & D'Arey, 2004) assert that prolonged exposure to high-intensity ultrasonic waves causes a significant tenderising of the meat, others have failed to confirm this effect (Lyng, Allen and Mckenna, 1997, 1998a,b). One study showed that sonication of beef muscle with an intensity of 2 W cm^{-2} for 2 h at a frequency of 40 kHz damages the perimysium resulting in improved texture (Roberts, 1991). To observe changes in maturation, Pohlman, Dikeman and Zayas (1997) applied ultrasound (20 kHz, 22 W cm^{-2}) for 0.5 or 10 min to shear pectoral muscles that had been vacuum-packed and ripened for 1, 6 or 10 days. The sonicated muscles showed reduced hardness with no effect of sonication time or storage of packed meat on weight loss, hardness or sensory characteristics. Non-packaged pectoral muscles that were treated ultrasonically had less weight loss than muscles processed by other methods.

A more recent report by Chang, Xu, Zhou, Li and Huang (2012) indicated that applying power ultrasound (40 kHz, 1500 W) to *semitendinosus* beef muscle for 10, 20, 30, 40, 50, and 60 min had no significant effect on colour but decreased the muscle fibre diameter with no effect on the content of heat-insoluble collagen, but with effects on the thermal stability and properties of collagen as well as the texture of meat. Kiwi protease enzyme (actinidin) participates in tenderising meat during marination, but if ultrasound (1 MHz, 150 W and 25 kHz, 500 W) is applied after injection of actinidin and meat is stored for 2 days, the marinating can be more uniform and effective (Jørgensen, Christensen and Ertbjerg, 2008) The combination of actinidin with ultrasound resulted in a further reduction of the toughness of the meat and the results suggest that the treatments weakened both the myofibrillar and the connective tissue components of the meat.

Another study showing that ultrasound can improve tenderness and the technological properties of meat was conducted by Jayasooriya, Torley, D'Arcy and Bhrandari (2007). These authors sonicated (24 kHz, 12 W cm^{-2}) bovine muscles for a maximum of 4 min and subsequently stored them. Sonication resulted in increases in tenderness and pH without significant interaction between ultrasound and maturation time. Ultrasound treatment did not affect the colour or drip loss, but cooking losses and total losses decreased. The hypothesis that ultrasound causes mechanical disruption and muscle tenderising has also been confirmed in poultry. In a study of hen breast muscles that were treated with ultrasound (24 kHz for 15 s at 12 W cm^{-2}) stored at 4 °C for 0, 1, 3, or 7 days, the shear force was reduced in the sonicated samples (Xiong, Zhang, Zhang and Wu, 2012) with no change in cooking loss. The results suggest that both ultrasound and endogenous proteases such as the calpain system and cathepsins contributed to muscle degradation.

2.1.2. Water holding capacity

It has also been shown that ultrasound facilitates release of the myofibrillar proteins, which are responsible for binding properties of the meat such as the water holding capacity (WHC), tenderness and cohesion of meat products (McClements, 1995). WHC changes depend on the post mortem changes in myofibrillar structure and therefore, the tenderness of the meat is related to the differences in the distribution of water during the conversion of muscle to meat (Lawrie & Ledward, 2006). Texture of meat is dependent on the WHC of meat, which is itself influenced by heating. When sonicated meat was cooked at 50 °C, it was softer than the control. However, when cooked at 70 °C, it was tougher than unsonicated meat as it appears that ultrasound treatment decreases water loss in refrigeration, thawing and cooking between 50 and 70 °C. Therefore, Dolatowski, Stasiak and Latoch (2000) suggest that ultrasound treatment could help change the textural properties of meat and increase the WHC after thawing and thermal processing without effect on the pH of the treated meat.

2.1.3. Maturation

The hypothesis that the application of ultrasound treatment may cause an acceleration of the maturation process has been repeatedly confirmed. Dolatowski and Stadnik (2007) and Stadnik and Dolatowski (2011) sonicated calf *semimembranosus* muscle at 24 h post mortem for 2 min and stored it for 24, 48, 72 or 96 h at 2 °C. No changes in pH or colour were observed, but there was an increase in the WHC in the sonicated samples, similar to that of the matured meat. Thus, the authors suggested that treatment with ultrasound accelerated *rigor mortis* since they also observed fragmentation in the structures of cellular proteins (Stadnik, Dolatowski and Baranowska, 2008).

In contrast, other studies have not confirmed the maturation effect of ultrasound on beef (Lyng, Allen and Mckenna, 1997, 1998a) or lamb (Lyng, Allen and Mckenna, 1998b) when using intensities from 0.29 to 62 W cm^{-2} for periods of 15 s and post mortem maturation times from 1 to 14 days. These authors found no changes in the hardness of the meat, chewing force, sensory characteristics, solubility of collagen or myofibrillar proteolysis. Comparisons between works cannot be made because equipment differences meant that intensities and frequencies of exposure were not similar between experiments. In other studies Got et al. (1999) treated *semimembranosus* muscle with ultrasound (2.6 MHz, 10 W cm^{-2}, 2 × 15 s) *pre rigor* (day 0, pH 6.2) or post rigour (day 1, pH 5.4) and found an effect only in the *pre rigor* condition. This treatment group displayed greater elongation of the

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