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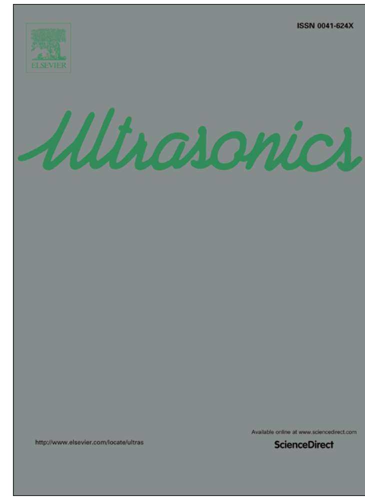

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Influence of extrinsic operational parameters on salt diffusion during ultrasound assisted meat curing

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Abstract

The present study investigated the effect of geometric parameters of the ultrasound instrument during meat salting in order to enhance salt diffusion and salt distribution in pork meat on a lab scale. The effects of probe size (Ø 2.5 and 1.3 cm) and of different distances between the transducer and the meat sample (0.3, 0.5, and 0.8 cm) on NaCl diffusion were investigated. Changes in the moisture content and NaCl gain were used to evaluate salt distribution and diffusion in the samples, parallel and perpendicular to ultrasound propagation direction. Results showed that 0.3 cm was the most efficient distance between the probe and the sample to ensure a higher salt diffusion rate. A distance of 0.5 cm was however considered as trade-off distance to ensure salt diffusion and maintenance of meat quality parameters. The enhancement of salt diffusion by ultrasound was observed to decrease with increased horizontal distance from the probe. This study is of valuable importance for the meat processing industries willing to apply new technologies on a larger scale and with defined operational standards. The data suggest that the geometric parameters of ultrasound systems can have strong influence on the efficiency of ultrasonic enhancement of NaCl uptake in meat and can be a crucial element in determining salt uptake during meat processing.

1. Introduction

Brining of meat is traditional process used for food preservation; during brining the meat is immersed in a saturated salt solution where it absorbs extra liquid and salt. The brine surrounding the muscle fibres has in fact a higher concentration of salt than the fluid in the cells, causing salt ions to enter the cell via diffusion. About 70% of the volume of lean meat is occupied by myofibrils which contain about 20% of protein, the rest being water. Myofibrils are responsible for the draw and retention of a substantial amount of water by both osmosis and capillary action, causing swelling to more than twice their original volume when immersed in salt solutions (Offer & Trinick, 1983). Brining of the meat is one of the major technologies used in processed meat manufacture, as it enhances shelf-life, flavour, juiciness and tenderness of the products. However, the migration of NaCl from the brine to the meat matrix is normally quite slow (Carcel, Benedito, Bon, & Mulet, 2007; Gou, Comaposada, & Arnau, 2003). Low frequency ultrasound, also known as power ultrasound, is employed in the food industry for accelerating brining processes and enhancing mass transfer. In meat processing, power ultrasound can modify cell membranes through cavitation, which can help with curing, marinating, dryin and tenderising the meat tissue, therefore helping in the enhancement of food quality and safety profile of the products (Ozuna, Puig, García-Pérez, Mulet, & Cárcel, 2013).

Ultrasound can in fact help reduce brining time without significant negative changes in other characteristics of the meat such as changes in quality (colour, texture, cook loss, expressible moisture), sensory attributes, oxidative stability and microbial load (McDonnell, Lyng, & Allen, 2014,Ojha, Keenan, Bright, Kerry, & Tiwari, 2016). Moreover, power ultrasound, acting on meat texture and providing a better distribution of salt in the meat matrix, could be helpful in the development of reduced salt meat formulations (Inguglia, Zhang, Tiwari, Kerry, & Burgess, 2017).

Even though is well documented that ultrasound allows faster and more uniform diffusion of the brine into the meat tissues comparing to static brining, and several studies reported a positive correlation between the use of ultrasound and improved meat quality in different tissues (Graiver, Pinotti, Califano, & Zaritzky, 2009; Leal-Ramos, Alarcon-Rojo, Mason, Paniwnyk, & Alarjah, 2011; Vestergaard, Andersen, & Adler-Nissen, 2007; Vestergaard, Erbou, Thauland, Adler-Nissen, & Berg, 2005; Wang, Tang, & Correia, 2000), there are also reported studies that did not show a significant effect on meat brining (Paulsen, Hagen, & Bauer, 2001) or in terms of improved meat texture or tenderness (Got et al., 1999; McDonnell et al., 2014). In general, it seems to be difficult to replicate brining experiments assisted by ultrasound, due to the different parameters and methodologies applied. The effect of ultrasound on meat brining processes is in fact influenced by various processing parameters, namely: medium characteristics, treatment parameters, generator performance, size and geometry of treatment vessel as well as probe size and distance (Berlan & Mason, 1992). After extensive research of the literature however, very limited information was found regarding the specific effect of probe size, and of the meat – probe distance, as parameters to look at to enhance the uptake of NaCl during ultrasound assisted brining. Therefore, the main aim of this work was to investigate operation parameters including i) probe size and ii) probe-meat distance, in order to provide additional information and ensure reproducibility on a lab scale of the optimal conditions to enhance NaCl diffusion during ultrasonic assisted curing of pork meat.

2. Material and methods

2.1 Raw material and sample preparation

Pork loin (*Longissimus dorsi*) muscle, obtained from a local supermarket was used for all experiments. Muscles were stored at 4 °C prior to being processed. The pH of all the muscles was 5.4±0.4, recorded by direct insertion of a pH electrode along the length of the muscle. Before curing, the connective tissue was carefully trimmed from the surface of the meat, and the muscles were cut into slabs of the same weight and size (100 ± 20 g; 8 x 4 x 2 cm as length, width and thickness). Sample location within the muscle was randomised with respect to treatment, and a new muscle was used for each experimental replication. From each pork loin muscle, 6-8 slabs were obtained.

2.2 Experimental design

The parameters investigated in this study were the effect of different ultrasonic horn size (Ø 2.5 and 1.3 cm) and the effect of different distances (0.3, 0.5 and 0.8 cm) between the tip of the sonotrode and the meat surface on NaCl distribution. NaCl content was used as a parameter to evaluate salt distribution and diffusion in the samples parallel and perpendicular to the ultrasound propagation direction. Starting from the centre of the slab, which is where the ultrasonic probe was held, the middle part of each meat piece was used for chloride determination; from this region, 15 small cubes were obtained by cutting the meat into three (A, B and C) layers vertically and five (centre to the edge: 1 to 5) columns horizontally, as shown in **Figure 1.**

The vertical distribution of NaCl was used to determine NaCl diffusion rate from the top surface, while the horizontal distribution was use to observe the effect of probe size on salt distribution. From the eight slabs obtained from each loin, four samples were randomly assigned to be cured using the large probe, while the other 4 were radiated using the small probe. Two pork loin muscles were used for a total of 16 samples processed. Similarly, to evaluate the effect of probe-meat distance, two pork loin muscles were used obtaining six pork slabs from each. Samples from the same muscle were randomly assigned to be processed using a distance of 0.3, 0.5 or 0.8 cm for a total a four replicates for each distance tested.

2.3 Brining treatment

Pork loins were fixed horizontally onto a basket in a tank filled with brine and treated by an ultrasonic probe held horizontally by a heavy duty stand at a fixed distance between the tip and the central surface of the sample. The ultrasonic head was kept fully immersed in the brine. Meat fibres were parallel to ultrasonic waves. The ratio between the meat and the brine was 1:40, much higher than what reported previously (Carcel et al., 2007; Ojha, Keenan, Bright, Kerry, & Tiwari, 2016; Siro et al., 2009). This higher ratio was chosen to ensure no variations in the salt concentration of the brine between treatments. All samples of each test series were treated individually. The samples were cured in ~ 4.5 L of 15% (w/w) NaCl brine solution dissolved in distilled water. The temperature of the brine was maintained at 2.5 ± 0.5°C by using a refrigerated circulator (LTD20G, Grant Instrument, UK) through which glycol coolant (− 0.5 °C) was circulated using a heat exchanger and a pump, (**Fig.2)**. The flow rate of the salt solution was about 1 L / min. The meat sample was fixed horizontally onto a basket in the tank and ultrasound (US) with a frequency of 20 kHz was irradiated on the sample for 60 minutes by using an ultrasonic processor (XL 2020, Misonix, USA). The US probe works with functionality between 0 and 100% power; the energy input was controlled by setting the power of the sonicator probe at 100% and the corresponding characteristics of the settings are described in **Table 1.** Ultrasonic power (P) was calculated as acoustic energy in 300 ml of water using equation (1) where: (dT/dt) is the change in temperature over time (°C min^{-1}), estimated from the slope of the temperature-time curve recorded every 10 seconds for 300 s, *C*p is the specific heat of water (4.18 kJ kg^{-1} $°C^{-1}$) and m is the mass (kg). The applied acoustic intensity (W cm^{-2}) was determined by dividing the ultrasonic power by the emitting surface area of the probe.

(1) $$P = mC_P\left(\frac{dT}{dt}\right)$$

The length of the ultrasonic treatment (60 minutes) was chosen based on preliminary experiments undertaken prior to this study. After curing, samples were rinsed with distilled water. The surface was blotted and the samples cut into sections as described in section 2.2.

2.4 Static brining process

Control meat samples were placed in a beaker, completely filled with 15% (w/w) brine solution and cured without any agitation for 60 and 240 minutes; 60 minutes time was used as direct comparison with sonicated samples, while the time point at 240 min was chosen as plausible time needed by the control samples to reach similar NaCl level to the sonicated samples (McDonnell, Lyng, Arimi, & Allen, 2014). After brining, samples were removed from the brine solution and treated as for sonicated meat samples. The initial temperature of the brine was of 3 ± 0.5°C, maintained constant by keeping the samples in a cold room (4 °C) for the whole curing time.

2.5 NaCl determination

The cured meat samples were cut into cubes accordingly to the experimental set up presented (**Fig.1**). Moisture analysis was determined by weight loss after overnight oven drying at 103 ± 2 °C (AOAC, 1990). For NaCl determination, samples were weighed into porcelain dishes, dried overnight and place on a Gallenkamp hot plate until completely burnt. The dishes containing the burned samples were then placed in the muffle furnace at 525 °C for approximately 8-10 hours and NaCl content was determined by the standard titrametric Volhard method (Kirk & Sawyer, 1991).

2.6 Quality analysis

Analysis were only performed for meat samples brined using the ultrasound probe system (Ø 2.5 cm) adjusted to the chosen distance of 0.5 cm from the meat top surface. The brining set up was the same as described in 2.3.

2.6.1 Cook loss and Texture

Samples were cooked at 77 °C for 65 min in a water bath until an internal temperature of 72 °C was reached. The cook loss was calculated as the weight change before and after cooking. Shear force was measured by Warner–Bratzler test performed on cylindrical cores (17ϕ × 20 mm) taken parallel to the longitudinal orientation of the muscle fibres from each cooked sample. Samples underwent a double axial compression (70%) at a speed of 50 mm/min with a 35 mm flat circular anvil attached to a 5 kN load cell on an Instron Universal testing machine (Model No. 5543, Instron, Bucks, UK). Warner-Bratzler (WB) shear and penetration force were taken as the maximum recorded force on the output expressed as Newton (N). A minimum of five replicate measurements were performed for each treatment.

2.6.2 Colour Analysis

Instrumental colour analysis was performed on both the surfaces of samples. Hunter L* a* and b* were determined as indicator of lightness, redness, and yellowness respectively. Measurements were done using a dual beam spectrometer Hunter Lab system (UltraScan XE, Hunter Lab., VA, USA). Illumination was matched to daylight (D65, 10°) with an 8° viewing angle and a 25 mm port size. Standardisation was performed using a light trap and a white tile. Readings were taken as the average of 6 measurements and the total color difference (TCD) was numerically calculated using the color difference before and after treatment using equation 2:

$$(2)\ \Delta E = \sqrt{(\Delta L*)^{2} \times (\Delta a*)^{2} \times (\Delta b*)^{2}}$$

2.6 Statistical method

Randomized complete block design was employed, and each piece of loin was treated as a block. Two way and Three-way ANOVA (SPSS 11.0 for Windows, Chicago, IL, USA), were employed to analyse the effect of horizontal position, vertical position and probe size. For the analysis of the quality parameters a Two-way ANOVA was used. Differences were considered significant at the $P < 0.05$ level.

<u>3. Results and Discussion</u>

3.1 Effect of ultrasonic probe size on NaCl distribution

Based on preliminary experiments, a distance of 0.5 cm between the probe and the meat and a power of 56 W and 54.7 W of the ultrasonic probes, were the parameters chosen to investigate the effect of probe size on NaCl content. It is known that smaller horn diameters deliver high ultrasonic intensity, but the ultrasonic energy transmitted to the meat surface is focused at relatively small concentrated area compared to larger horn diameters. As expected, despite the lower intensity delivered, the employment of the larger probe led to a higher overall NaCl content, which can mainly be attributed to the higher salt contents gained in the upper section (A1) and in layer C; data are shown on the upper section of **Table 2.** The large probe covered most part of the central meat section, specifically up to the section A2, while the small probe was exactly within the area designated as A1. However, even with larger area covered by the probe, no higher salt content was observed in section A2, probably due to the lower ultrasonic intensity delivered in this area. Statistical data showed significant differences in the interaction between the meat sections (A, B, C) and the relative distance from the probe (1-5) on the NaCl content of pork meat sonicated with a probe size of 2.5 cm ($F = 9.352$, $p < 0.0005$), and samples sonicated with a probe of 1.3 cm ($F = 6.462$, $p < 0.0005$).

3.1.1 Horizontal NaCl distribution

Looking at the horizontal NaCl distribution (sections 1-5), the overall higher salt content in layer A, could be attributed to the centre section (e.g. A1) right below the probe, in which values got as high as 7.1% (Ø 2.5 cm) and 6.51% NaCl (Ø 1.3 cm), both significantly ($P < 0.05$) higher than in the other respective sections, **Table 2**. Salt contents values decreased to 3.16% and 2.84% (section A3) respectively for the large and small probes, further decreasing as the sections were farther away from the probe. On the other hand, at the bottom layer, NaCl content seemed to be higher in the outer regions compared to the centre of the section, regardless of the probe size used. However, the variation in NaCl content between the sections was < 1% which is lower compared to layer A where NaCl variation between the sections was > 4%. In layer B, the sections B1, B2 and B5 had significantly ($P < 0.05$) higher salt contents than the central section B3 and B4. The variation of NaCl between two neighbouring sections in layer B, however, was much smaller than the variation between two neighbouring sections in a same column. It is interesting to notice that only within column 1 the salt content in the middle layer (B1) was higher than at the bottom (C1). Observing the NaCl variation in this first column, it can be seen how power ultrasound can strongly enhance the vertical mass transfer in the meat matrix, going as deep as almost 2 cm in the meat matrix. The horizontal enhancement effect on NaCl distribution however seemed to be negligible and appeared to be limited to the area in the immediate vicinity of the probe, despite the intensity delivered. Similarly, it was observed by McDonnell et al. (2014a) that US energy was more concentrated at the surface phenomenon, demonstrating the importance of further optimisation studies. In a similar study, Carcel et al. (2007) investigated the effect of ultrasonic intensities ranging from 14.7 ± 0.6% to 75.8 ± 2.6% and probe diameter (1.3 and 0.6 cm) on NaCl diffusion in the pork meat matrix; comparably, they observed that the ultrasonic intensity enhanced the amount of NaCl gained in the meat compared to static brining.

3.1.2 Vertical NaCl distribution in the meat layers

The data generated by NaCl determination of the vertical sections 9 (A-C), showed that the top layer (layer A), which directly faced the probe, had significantly ($P < 0.05$) higher salt content than the other layers as shown in **Table 2**. The bottom layer (layer C) however contained more salt than the middle layer (layer B), regardless of the probe size. This observation could be explained by the effect of the propagating ultrasonic waves throughout the solution in the tank having an impact on all the exposed surfaces of the meat, including the bottom surface. The higher salt concentration present at the top surface can be easily be attributed to the enhancing effect of ultrasonic cavitation, possibly via formation of microjets near the surface (Mason & Lorimer, 2003). The overall higher NaCl content distributed on the bottom layer (C), 0.6 and 1% more than layer B, respectively for the 1.3 and 2.5 cm probe heads, is reasonably given by the higher exposure of the surface with the brine, guiding the movement of the salt into the meat matrix. Similar NaCl values were observed also in the control sample, showing a difference of ≈ 2% more NaCl in layer C than B, **Table 2** (lower section). It is interesting to notice in the control sample cured for 60 minutes that the top surface (A1-A4) gained considerably less NaCl than the bottom surface, even though there was no apparent difference between the two sides. This characteristic was not observed in the control samples cured for 240 minutes: the two sides showed a similar NaCl distribution. In particular, the sections at the edges were the ones where the NaCl gain was higher, up to 3.5% and 5.5% for the samples cured for 60 and 240 minutes. Possibly this was caused by the major exposure to the brine, favouring, over time, osmotic migration of NaCl into the meat. Despite the higher intensity of the smaller probe, statistical data of the three-way interaction between probe size, different sections and positions, showed no significant difference ($F = 0.168$, $p = 0.995$) in the overall NaCl distribution.

3.2 Effect of ultrasonic probe – meat distance on NaCl diffusion

By using the bigger ultrasonic probe head (Ø 2.5 cm) fixed at distances of 0.3, 0.5 and 0.8 cm from the meat surface, the effect of the probe – meat vicinity on NaCl distribution pattern in the meat matrix was investigated; results are presented in **Table 3**. In all cases, the top layer had significantly ($P < 0.05$) higher salt (>4%)

contents than the bottom layer, reaching around 2% NaCl, while the bottom layer contains higher NaCl than the middle layer (<2%). Column 1 had the highest NaCl content, which decreased with an increased horizontal distance from the probe ($P < 0.05$) i.e., from column 1 to column 4. A distance of 0.3 cm led to an overall higher NaCl gain (3.05 ± 2.41%) than a distance of 0.5 cm away from the meat surface (2.82 ± 2.16 %) and, consequentially, 0.5 cm resulted in a higher NaCl content than 0.8 cm (2.3 ±1.58 %, $P < 0.05$).

The salt content differences between the 3 probe distances were mainly observed in sections A1, A2, B1 and B2. It is interesting to notice that NaCl contents in section B1 for 0.3 and 0.5 cm distances, were considerably higher (4.4% and 3.05%) than in C1 (2.52% and 2.01%), while this was not the case when the probe was fixed at 0.8 cm from the meat, giving NaCl value of 1.23% in B1 and 2.01% in C1. This observation underlines the role of distance in enhancing the effect of power ultrasound on mass transfer in the meat matrix. Even with such a short difference between the variables tested, the NaCl gained could not reach the same values registered for sample treated at 0.3 and 0.5 cm of distance. The decrease in NaCl content from column 2 to column 3 in a similar layer (e.g. A2 to A3, 6.68 to 3.04% and B2 to B3, 2.17% to 0.38%) however, showed again that the effect of ultrasound is significantly reduced with an increased horizontal distance from the probe ($F = 3.409$, $p = 0.001$).

3.3 Effect of sonication on brined pork quality

Macroscopic observations of the effects of power ultrasound on the meat matrix when different distances were used can be observed in **Figure 3.** Closer distances had a higher impact on the meat surface due to the generation of local pressure and high temperature, and consequentially resulted in higher NaCl uptake. The picture showed an obvious white colour mark on the surface, just below the probe. The meat fibre in the mark appeared to be denatured or cooked. Previous studies using ultrasound at 20 kHz, 22 W cm^{-2} for 5 or 10 min reported of changes in colour which were characteristic of cooked meat, stating that the cooling vessel may not have worked efficiently (Pohlman, Dikeman, & Kropf, 1997). In this experiment, even though the temperature of the system was maintained at 4 ^{o}C, local high temperature due to the cavitation effect may have been causing the marks (Mason & Lorimer, 2003). Such an effect could only be seen on sample surfaces when cured at 0.3 cm distance. NaCl can in fact cause swelling of muscle fibres resulting in expansion of the meat slabs, reducing even further the distance between the probe and the meat surface (Offer & Trinick, 1983; Siro et al., 2009). This mechanism could explain the differences observed on the meat surface, and justify the different NaCl uptake (9 and 4.04%, 8.04 and 3.05% NaCl) for A1 and A2 sections, even with a short variation in the distance used, 0.3 and 0.5 cm respectively.

Further quality studies were performed on samples treated by keeping the probe head at 0.5 cm of distance from the meat surface, and are presented on **Table 4**. This parameter showed a threshold between the required NaCl uptake for meat products (~ 2.20%) and maintenance of quality parameters and therefore, was the only one chosen to be further considered (Pegg, 2004). No significant difference ($p > 0.05$) was observed in the moisture content between samples treated with different probe sizes and intensities or using different distances compared with control samples. The moisture content of various US treated or control samples varied from 77 to 69% (samples treated with different probe sizes), to 76.5 to 71.9% (samples treated using different distances) and from 75.6 to 70.9% for the control samples (data not shown). Similar results were observed by McDonnell, Lyng, Arimi, and Allen (2014) with power intensities used of 10.7, 17.1 and 25.4 W cm^{-2}.

Sonicated samples, showed significant difference in the curing yield (p = 0.046) but no significant differences in terms of cooking losses (p = 0.070). For colour change, the presence of the white mark caused by the ultrasound lead to statistically different (P = 0.012) colour between the two treatments. Despite this, from a visual point of view, no perceivable colour change was observed in this case. According to Francis and Clydesdale (1976) when $\Delta E > 3$, colour differences are obvious for the human eye, and values in a scale from 2-10 can be define only as "perceptible". In this study, TCD values for sonicated (ΔE, 6.26) and non - sonicated (ΔE, 10.69) samples fall in this range.

Conclusion

The aim of this study was to provide additional information valuable to the available pool of studies which have been done on ultrasound assisted brining, to narrow down, on a lab scale, the conditions for possible industrial application. Different extrinsic parameters to optimise the application of ultrasound technology to assist meat brining and therefore, to improve NaCl uptake and its distribution in pork meat were investigated. Between the two investigated variables i) probe size and ii) probe- distance, the latter seems to be the limiting factor in the efficiency of ultrasound assisted brining. As previously reported by other authors, the enhanced mass transfer with no effect on quality attributes suggests that ultrasound could be a surface phenomenon, most active at the interface with the saline solution. According to the results presented, ultrasound can have an enhancing effect up to almost 2 cm deep in the meat matrix. However, this effect significantly decreases moving farther away from the probe, and also with an increased horizontal distance. A lower ultrasound intensity but with a larger emitting area, is suggested as good strategy to maximize NaCl uptake in meat. In the scenario where a much bigger meat piece would be processed, the use of an ultrasound probe to assist meat brining should be intended to directly cover as large an area of meat as possible, or otherwise, a number of ultrasound transducers per unit of area could be arranged to improve the effectiveness of ultrasound for the same ultrasound power level. Moreover, the possible use of smaller brine to meat volume ratio, would favour a more concentrated energy in the liquid allowing a better effect of the ultrasound. From the point of salting rate, shorter distances between the probe and the meat surface (0.3 or 0.5 cm) are suggested as a geometrical operation parameter when an ultrasound probe is employed to assist salting meat processing. Increasing the distance of the probe to 0.5 cm has been shown to be sufficient to ensure high NaCl uptake without significantly impacting the quality of the meat product. According to the parameters investigated, the curing time needed to reach the required NaCl level in the meat with power ultrasound was at least four times shorter than standard immersing technique, further reducing the time reached by McDonnell et al. (2014) and confirming the potential application and advantage of ultrasound assisted meat curing.

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List of figures

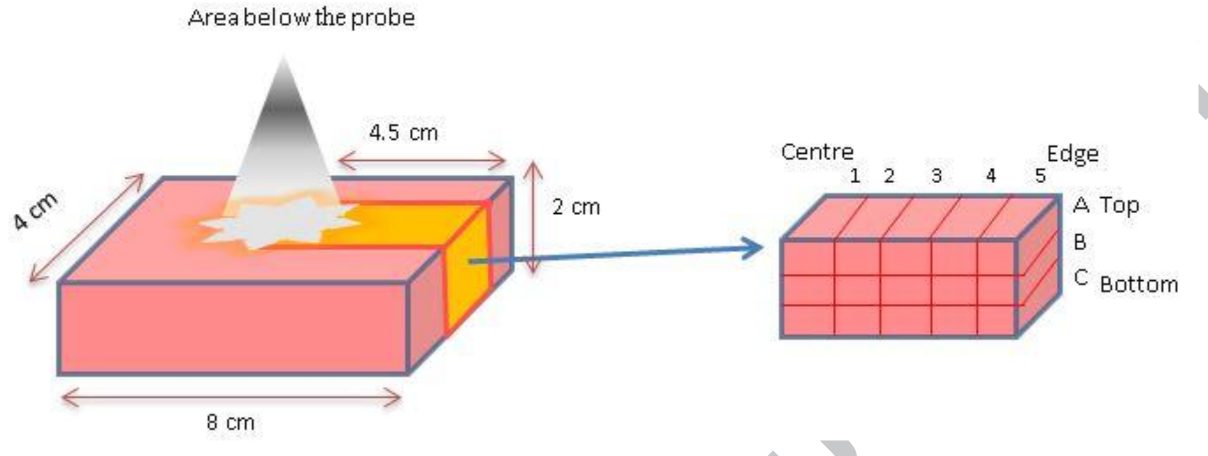

Figure 1. Schematic model of the sample geometry with details on the 15 regions used to determine NaCl distribution in cured pork loin slab.

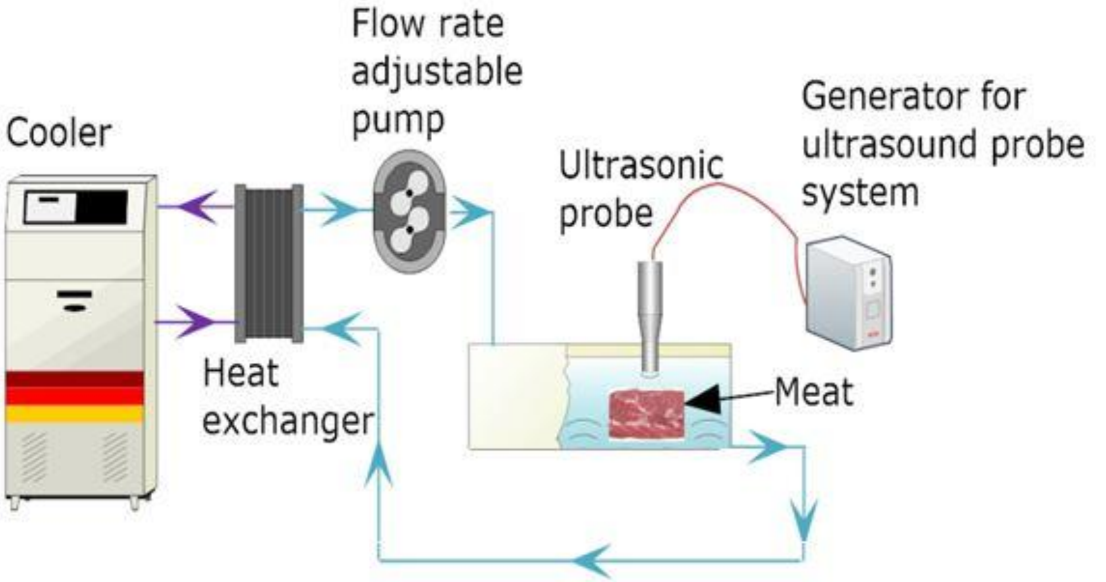

Figure 2. Schematic diagram of experimental set-up. The system used was composed of a refrigerated circulator (cooler), through which glycol coolant (− 0.5 °C) was circulated using a heat exchanger and a pump, The meat sample was fixed horizontally onto a basket in a tank filled with 15% brine solution. Ultrasound (US) with a frequency of 20 kHz was irradiated onto the sample for 60 minutes by using an ultrasonic processor.

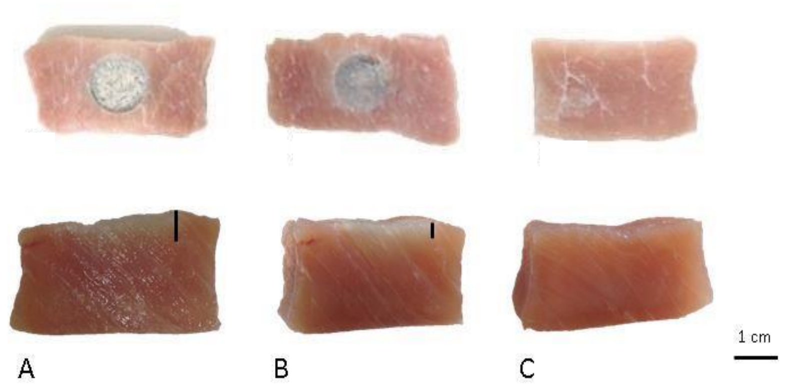

Figure 3. Impact of ultrasound with different distances between the probe head and the meat matrix. The figure show the effect of the ultrasonic probe fixed at different distance from the meat surface. A) Distance of 0.3 cm. B) Distance of 0.5 cm. C) Distance of 0.8 cm. Top picture: whole meat slab from the top. Bottom picture: central area of the pork slab in section. The black bar (ref. 1 cm), indicates the depth reached by the ultrasound effect in the meat.

List of Tables

Table 1. Ultrasonic probe characteristics and treatment times (min) used to study NaCl diffusion in pork loin slab.

	Treatment	Treatment time (min)	Power output (%)	Amplitude (μm)	Power (W)	Intensity (W cm^{-2}) [1]
Probe Ø 2.5cm	US	60	100	35	56	22.21
Probe Ø 1.3cm	US	60	100	114	54.7	41.22
Control	No US	60	0	0	0	0
Control	No US	240	0	0	0	0

[1] Ultrasonic intensity was calculated by dividing the power output measured by calorimetry by the area of the emitting surface (2.521 and 1.327 cm^2)

Table 2. Effect of probe size on NaCl distribution in the meat sections.

Probe size Ø (cm)	Treatment time (min)	Vertical position	Horizontal position				
			1	2	3	4	5
2.5	60	A	7.10±1.80^a	5.05±2.23^a	3.16±1.61^b	2.33±0.78^b	2.77±0.66^b
	60	B	1.65±1.30^a	1.27±0.95^a	0.50±0.29^a	0.34±0.15^a	1.67±0.70^a
	60	C	1.59±0.58^a	1.74±0.39^a	1.97±0.77^a	2.04±0.73^a	3.25±1.84^b
1.3	60	A	6.51±2.57^a	5.23±2.68^a	2.84±1.23^b	2.18±0.84^b	2.82±0.75^b
	60	B	1.66±1.03^a	1.35±1.03^a	0.38±0.22^b	0.40±0.11^b	1.16±0.30^a
	60	C	1.24±0.51^a	1.33±0.62^a	1.38±0.48^a	1.71±0.54^a	2.49±0.43^a
Control	60	A	0.66±0.18^a	0.80±0.39^a	1.07±0.72^a	1.30±0.47^a	3.52±0.82^b
	60	B	1.37±0.68^b	0.90±0.24^a	0.47±0.19^a	0.21±0.09^a	1.94±0.37^b
	60	C	1.68±1.05^a	2.72±0.58^a	2.03±0.77^a	4.23±2.33^a	4.02±1.88^a
Control	240	A	3.59±1.75^a	2.02±1.70^a	3.32±1.94^a	3.77±0.93^a	5.56±0.34^b
	240	B	0.71±0.12^a	0.80±0.13^a	0.40±0.15^a	0.61±0.15^a	2.35±1.54^b
	240	C	3.43±2.43^b	3.27±1.09^b	2.83±1.25^b	1.84±0.21^a	4.36±1.63^b

NaCl content (%) of 15 regions of pork loin samples cured in 15% brine solutions using two probe sizes. Values represent means ± SD (N=8). Control samples were cured in static conditions (no US) with 15% brine solutions per 60 and 240 minutes. Values represent means ± SD (N=3).

$^{A, B,C}$ indicate the vertical distribution in the layers (Top –Bottom);

$^{1\text{-}5}$ indicate the horizontal distribution (from below the probe – edge); Ref to Fig.1.

^{abc} Values followed by different letters in the same row are significantly different at $P < 0.05$.

Table 3. NaCl distributions (%) of pork loin sample cured using different probe–meat distances.

Distance (cm)	Vertical position	Horizontal position				
		1	**2**	**3**	**4**	**5**
0.3	A	9.00±0.97[a]	6.68±1.77[b]	3.04±0.56[c]	2.25±0.37[c]	3.11±1.16[c]
	B	4.04±3.17[a]	2.17±1.39[a]	0.38±0.09[b]	0.31±0.06[b]	1.85±0.48[b]
	C	2.52±1.51[a]	2.39±1.04[a]	2.23±0.76[a]	2.49±0.75[a]	3.35±0.85[a]
0.5	A	8.04±1.07[a]	6.49±1.10[b]	2.80±1.51[c]	2.03±0.14[c]	2.83±0.44[c]
	B	3.05±1.48[a]	2.63±1.16[a]	0.56±0.28[bc]	0.46±0.13[bc]	1.51±0.24[ac]
	C	2.01±0.42[a]	2.07±0.70[a]	1.96±0.38[a]	1.95±0.07[a]	2.76±0.32[a]
0.8	A	5.55±1.42[a]	4.69±1.98[a]	2.82±0.65[b]	2.52±0.44[b]	2.87±0.46[b]
	B	1.23±0.51[a]	0.82±0.14[a]	0.43±0.12[a]	0.39±0.08[a]	1.29±0.56[a]
	C	2.01±0.45[a]	2.38±0.73[a]	2.34±0.69[a]	2.35±0.52[a]	3.04±0.57[a]

Sample were treated with a 2.5 cm diameter probe, operating with a frequency of 20 kHz and a power of 56 W.

Values represent means ± SD (N=4).

[A, B, C] indicate the vertical distribution in the layers (Top –Bottom);

[1-5] indicate the horizontal distribution (from below the probe – edge); Ref to Fig.1.

[abc] Values followed by different letters in the same row are significantly different at $P < 0.05$.

Table 4. Quality parameters of selected sample . Comparison in total NaCl content and quality parameters between sonicated[*] (US) and non-sonicated (Control) pork loin samples brined in a 15% (w/w) brine solution for 60 minutes. Values represent means ± SD (N=4).

	Curing time (min)	**Total NaCl content (%)**	**Moisture content (%)**	**Curing yield (%)** [**]	**Cooking loss (%)**	**Firmness (N)**	**TCD (ΔE)**
US	60	2.23±0.07[a]	73.52±0.68[a]	0.72±0.03[a]	14.16±1.04[a]	28.58±3.65[a]	6.26±0.74[a]
Control	240	2.21±0.50[a]	72.54±0.83[a]	-1.38±0.46[b]	22.08±5.48[a]	19.51±4.05[b]	10.69±1.61[b]

* Sonication was performed with a 2.5 cm diameter probe fixed at 0.5 cm distance from the meat surface, operating with a frequency of 20 kHz and a power of 56 W.

[**] Negative curing yield means weight loss after curing in comparison with weight before curing.

[abc] Values followed by different letters in the same column are significantly different at $P < 0.05$.

Research highlights

1. Effect of geometric parameters on salting of meat
2. Ultrasound can enhance salt diffusion and salt distribution in pork
3. Salt distribution can be improved using ultrasound