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Processing Smoked Pork Loin Using Ultrasound-Assisted Curing

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Abstract: The objective of this study was to evaluate the impact of high intensity ultrasound (HIU)-assisted brining on the physicochemical characteristics and consumer preference of smoked pork loin (*Longissimus dorsi*, LD). LD cuts (5 × 8 × 2.5 cm, length × width × height) were randomly distributed in a 2 × 2 design of two concentration of brine (5 or 10% NaCl) and two methods of brining (static, TC; or HIU for 30 min). After brining, the samples were smoked, cooled, vacuum packed and stored for 7 d at 4 °C. Weight, pH, percentage of NaCl, water-holding capacity (WHC), shear force and colour characteristics were evaluated in post-brining and smoked samples. Sensory analysis was performed to evaluate preference in appearance, taste, and texture characteristics. Weight and NaCl increased in samples post-brining. However, smoked pork samples were not significantly different among treatments. The smoked samples became more yellow and less red. Consumers preferred TC smoked pork based on this appearance characteristic. HIU improved NaCl concentrations in cured pork meat. Under these conditions, it is necessary to consider the posterior treatment that the ultrasonicated-cured meat will undergo, since part of the weight gain was lost during the smoking process.

Keywords: curing; mass transfer; high intensity ultrasound; brine; sensory analysis; smoked pork

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1. Introduction

Curing is a conservation technique that has been widely used since ancient times to prolong the shelf-life of meat. It consists of exposing the meat to a mixture of sodium chloride and nitrate/nitrite. However, a high sodium intake is detrimental to human health and is a major dietary risk factor for cardiometabolic mortality [1]. Additionally, the smoking of the meat is a process that complements the curing. It is defined as the procedure by which smoke is applied to foods to give them flavour and reinforce their colour, odour, or both, and can prolong their shelf life [2,3]. Therefore, it is of practical importance to research technologies for curing and salt reduction in order to develop high-efficiency processes to produce healthier foods such as pork tenderloin.

Ultrasound (HIU) is a potential method to speed up the salting or curing process in meat products. Nowadays, there is considerable information on the mechanical action of ultrasound enhancing mass transfer and the potential of ultrasonic energy for accelerating the salting of meat. For instance, Cárcel et al. [4] demonstrated that the mass transfer is proportional to the applied ultrasonic intensity without influencing the geometry of the sample. In particular, the diffusivity of NaCl and the effective humidity are improved by the application of ultrasound [5]. The final content of NaCl and moisture and the application of ultrasound promote microstructural changes in the meat, resulting in the improvement of the meat texture.

Additionally, HIU reduces the curing processing time regardless of intensity if it is higher than 10 W/cm^2 [6]. No effect of ultrasound was observed in the diffusion of a brine

(5% NaCl) at 9 W/cm^2, but the mass transfer increased when the intensity was increased to 54.9 W/cm^2 for 120 min [7]. However, there is separation of myofibrils, which results in a constant rupture, when the intensity is 20.96 W/cm^2 [8]. These structural changes are more marked after 48 h of sonication, which results in higher tenderness and acceptance of pork loin meat [9]. Homogeneous distribution of the solute was achieved in beef at 11 W/cm^2 and 40 kHz [10]. Likewise, the changes are more accelerated when HIU (37 kHz, and 22 W/cm^2) is applied to thinner samples (1.27 cm vs. 2.5 cm). HIU remarkably reduces shear force, increases the mass transfer, the water holding capacity (WHC) and the amount of salt. Furthermore, the meat is juicier and more tender when it is ultrasonicated for 30 min than when sonicated for 90 min [11]. The geometric parameters of ultrasound systems can also have a high influence on the effect of ultrasonication on the absorption of NaCl in meat. The most efficient distance between probe and sample is 0.5 cm in terms of ensuring a higher rate of salt diffusion and the quality of the meat [12]. The effect of HIU on speeding up the curing in meat has also been tested on rabbit [13].

Information about the HIU-assisted curing effects on the healthy characteristics of meat with reduced salt levels is scarce. Ultrasound has recently been suggested as a potential practical technique to improve the quality of reduced-sodium (1.5% NaCl) bacon. Additionally, favourable changes in the texture and sensory qualities of bacon after the application of 300 W for 60 min have been reported [14], and improvements in lipid oxidation, protein oxidation and the formation of free amino acids after the application of 600 W for 30 min has been reported. This improves the taste by promoting the release of volatile phenolic compounds and aldehydes [15]. Therefore, ultrasound as a potential method to speed up the brining process in cured and smoked meat products can also be a practical technique to improve the quality and flavour of products with reduced sodium content.

Besides, HIU is a safe technology to be applied in food. Since HIU is non-human perceptive acoustic phenomenon, there are not residues in the treated food. There are not any relevant studies reporting on health risks in consumers, but nevertheless, some risk may appear on occupational personal exposure to HIU in foods. In this sense, it is necessary to develop studies evaluating the risk in order to recommend times and doses of exposure [16].

Based on this information, this study aimed to evaluate the effect of HIU-assisted brining on the technological characteristics, salt concentration, and preference of cured and smoked pork loin (*Longissimus dorsi*). The results will allow for the expansion of knowledge on the use of HIU in the enhancement of low-sodium cured products.

2. Materials and Methods

2.1. Sample Preparation

Longissimus dorsi muscles were obtained from one Duroc × Yorkshire pig (120 ± 10 kg live weight) slaughtered at a commercial meat-processing company under standard commercial conditions. The muscles were received at −20 °C, and they were cut into 2.5 cm slices, perpendicular to the muscle fibres, making a total of 40 samples. These were randomized and vacuum packed. Steaks were thawed at 4 °C for 48 h and then trimmed of subcutaneous fat and connective tissue. The thawed slices were cut into 5 × 8 × 2.5 cm portions. The technological characteristics of the fresh samples are shown in Table 1. pH was used as an indicator of normal (non-pale, soft and exudative) pork.

Table 1. Technological characteristics of the pork *Longissimus dorsi* samples used in the experiment (mean and standard deviation, S.D.).

Characteristic [1]	Mean	S.D.
Weight, g	84.45	8.81
L*	51.88	3.45
a*	7.33	1.54

Table 1. *Cont.*

Characteristic [1]	Mean	S.D.
b*	6.03	1.67
Chroma	9.52	2.12
Hue angle	39.99	4.26
pH	5.67	0.14
WHC, %	59.68	2.90
Shear force, kg	2.95	0.50

[1] L* = luminosity, a* = redness, b* = yellowness, WHC = water holding capacity. S.D. = standard deviation.

2.2. Treatments

Each sample was placed in a glass bleaker containing 300 mL of brine. Samples were marinated by immersion for 30 min (15 min/side). HIU-assisted marination was performed using a UP400St ultrasonic processor system (Hielscher, Teltow, Germany. 24 kHz, 106 W/cm^2). Distilled water at 4 °C was used as a coupling medium in the external chamber. A constant temperature was maintained during treatment using ice cubes (Figure 1).

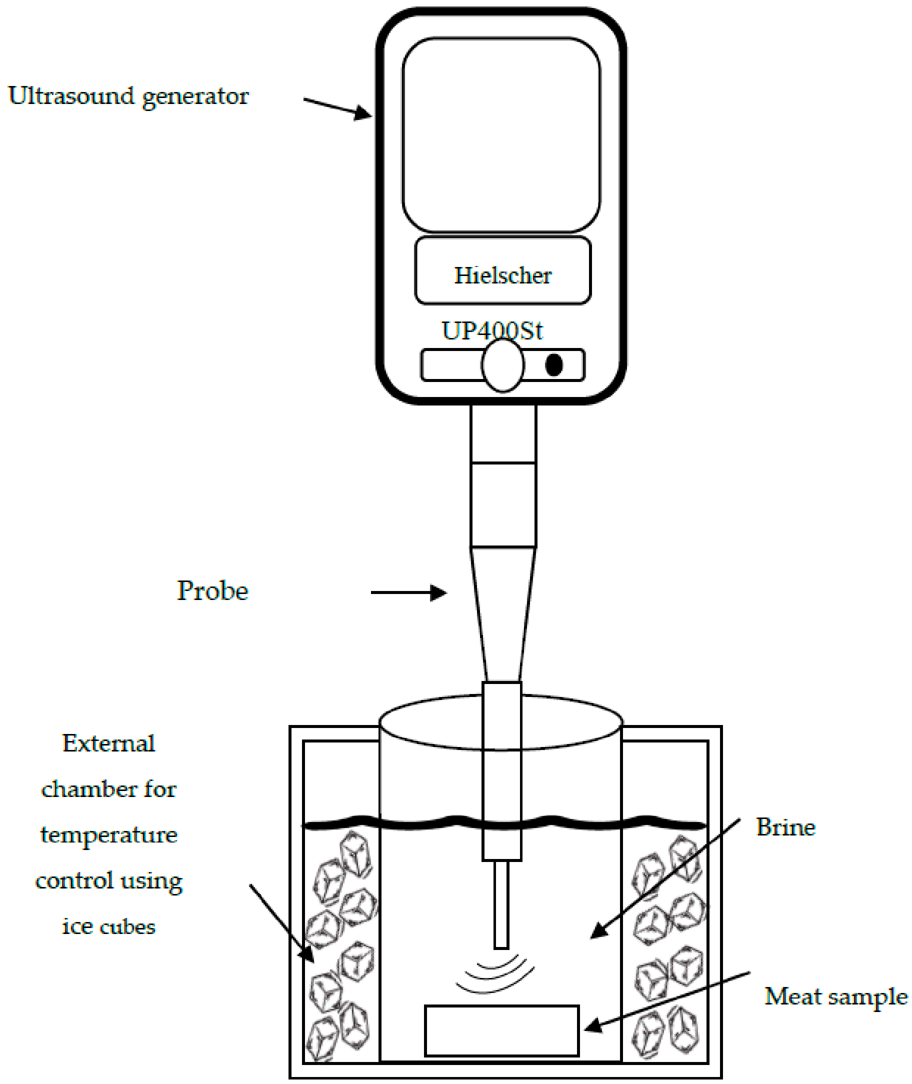

Figure 1. Ultrasound application.

The experiment included four treatments (5 or 10% NaCl × ultrasonication or control) with five repetitions each. Hence, 20 samples were processed for the physicochemical analysis and 20 for the sensory analysis. After marination (brining or HIU), the samples were vacuum-packed (polyethylene bags 70 calibre, processed in a Koch®, Easypack™ vacuum packer, Kansas city, USA) and stored for 7 d (4 °C). After the storage, the technological variables and sensory acceptability of the sample were evaluated.

2.3. Brine Preparation

The brine ingredients for all the treatments were 20 g of nitrites, 10 g of standard sugar, 3 g of sodium erythorbate and 30 g of polyphosphates dissolved in 1000 mL of purified water. In addition, 50 g (5%) or 100 g (10%) of NaCl were added to obtain the two tested concentrations of sodium chloride. Brine temperature was maintained at a constant 4 °C.

2.4. Smoking Process

An industrial-type indoor gas smoker and pine–oak sawdust were used for the smoking process (Figure 2). The samples were removed from the packaging and placed in an elastic mesh. The internal temperature of the smoker was 100 ± 10 °C with a humidity of 40–70%. The samples were removed from the smoker upon reaching a temperature of 62 ± 2 °C at their geometric centre, approximately 70 min after the process started [2], then the mesh was removed, and the samples were cooled at room temperature. Later, the smoked samples were vacuum packed and aged for a period of 7 d at 4 °C.

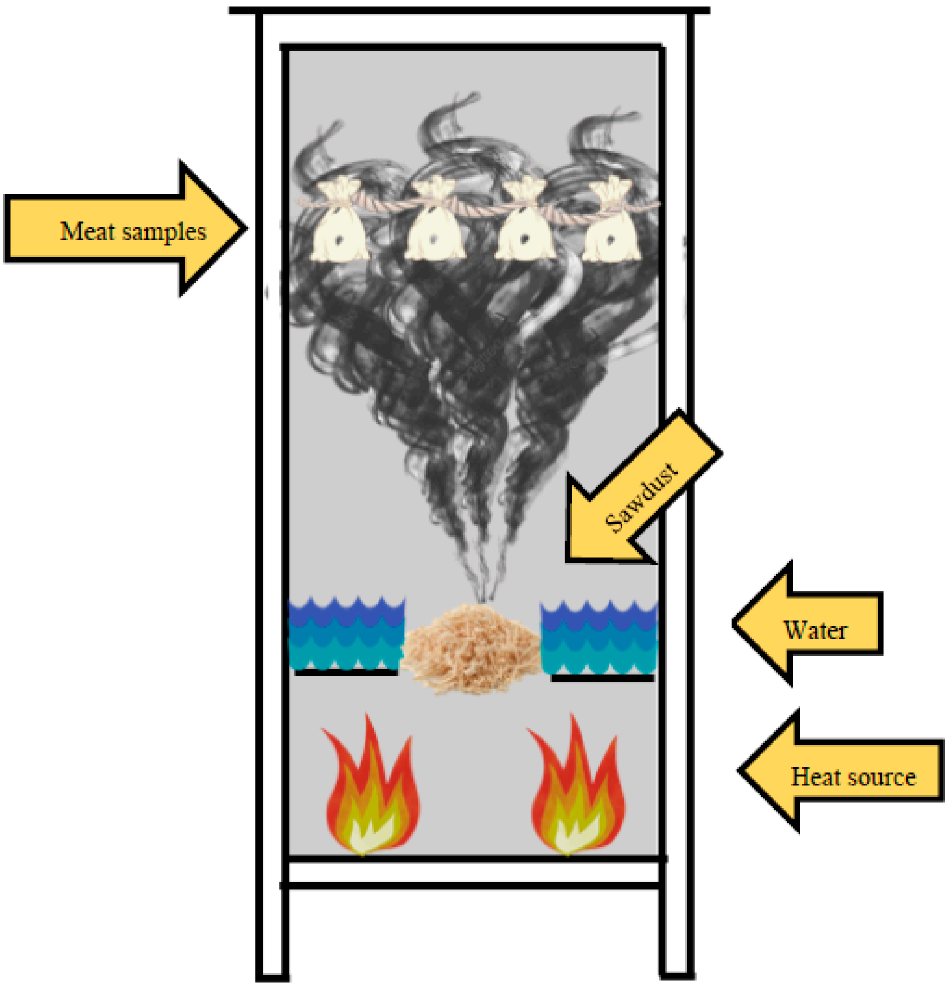

Figure 2. Schematic of the gas smoker with pine–oak sawdust.

2.5. NaCl Determination

The percentage of NaCl (chlorides) in the samples was evaluated in triplicate after the brining treatment, after smoking, and after the storage period using the methodology described by Mohr [17]. Twenty-five grams of sample were homogenized in a beaker containing 50 mL of distilled water and later boiled. The sample solution was filtered (Whatman No. 4 filter paper) after being cooled and was then transferred to a 100 mL volumetric flask. Five ml of the filtrate were taken in a 125 mL Erlenmeyer flask, and three drops of $K_2Cr_2O_7$ were added. Finally, the sample was titrated with a 0.1 N $AgNO_3$ solution, until an orange-coloured solution was obtained. The percentage of salt was calculated in triplicate. The NaCl percentage was calculated using the following equation: % NaCl = ml of 0.1 N $AgNO_3 \times 0.467$.

2.6. Technological Quality

The technological variables of pH, water holding capacity (WHC), shear force, colour and weight of the samples were evaluated in fresh meat, after brining, after smoking and after aging.

2.6.1. pH Measurement

The pH of the meat was recorded randomly at three locations using a pH meter (99163, Hanna Instruments, Woonsocket, RI, USA). Three random readings were taken, and the averages were recorded. The probe was previously calibrated at 4 °C with calibration solutions with a pH of 4.0 and 7.0. The probe was inserted in the muscle to a depth of 2 cm avoiding contact with fat and remnant connective tissue. Three random readings were performed in three different parts of the sample, and the averages was recorded.

2.6.2. WHC Determination

WHC was determined by using the press method proposed by Tsai and Ockerman [18]. A sample of approximately 0.3 g was weighed on an analytical balance and placed between two filter papers (Whatman No. 1), which in turn were placed between two plexiglass plates (15 × 15 cm), upon which a constant 10 kg pressure was applied for 20 min. WHC was expressed as the percent difference in sample weight before and after pressure application.

2.6.3. Shear Force (SF) Analysis

SF analysis was performed using the Warner–Bratzler method according to the AMSA methodology [19]. The samples were placed in airtight plastic bags and cooked in a water bath (Isotemp 215, Fisher Scientific, Pittsburgh, PA, USA) at 85 °C until reaching 72 °C at the geometrical centre of the sample. Cooked samples were tempered at room temperature and left to cool at 4 °C overnight. After 24 h, nine cores (1.25 cm diameter) per sample were cut parallel to the muscle fibres using a punch. Cores were sheared using a TA.XT2i (Stable Micro Systems, Surrey, UK) with a V-shaped blade attached to a 30 kg load cell at a crosshead speed of 120 mm/min. SF values were reported as kgf.

2.6.4. Colour Measurement

The colour of samples was measured using a Minolta Chroma Colorimeter (CR-400 Konica Minolta Sensing, Inc., USA) after 20 min of exposure to air. A CIE (Commission Internationale Pour lÉclarige) reference system was used following AMSA methodology [20]. Values were expressed as L* (luminosity), a* (redness), b* (yellowness), C* (chroma) and H* (hue angle).

2.7. Consumer Preference Test

A paired preference test was carried out in order to evaluate the application of ultrasound's effect on the consumer acceptability of cured and smoked pork loin [21]. The consumer population consisted of 90 students from the Department of Animal Science and Ecology. The study was reviewed and approved by the Institutional Bioethics Committee of the Faculty of Animal Science and Ecology of the Autonomous University of Chihuahua, Mexico (Decision No. P/302/2017), and informed consent was obtained from each subject prior to their participation in the study. The recruitment process was conducted via videoconference invitation. Consumers were recruited based on the following criteria: (a) like for meat products, (b) consuming cured products at least once a week, and (c) interest in participating in the study. Eight sessions of a maximum twelve different consumers each were carried out. The test was performed in the Sensory Analysis Laboratory equipped with 12 cabins and white light (fluorescent). Two samples were coded with random three-digit numbers and simultaneously presented in a randomized design [22]. Panellists were asked to rinse their mouth with water before evaluating each sample. The panellists were asked to identify the sample that they preferred. In this test the subject was forced to make a choice [21].

2.8. Statistical Analysis

A completely randomized factorial (2 × 2. NaCl in brine at 5 or 10% × curing method; sonication, HIU; or traditional, TC) design was used for analysis. The treatments and their interaction effects were evaluated on pH, colour characteristics (CIE L*, a*, b*, hue, chroma), WHC and SF. All the tests were performed in triplicate except for the SF test (9 samples). ANOVA was performed, and the differences between samples were determined using Tukey tests (significance level $p < 0.05$) [23]. The sensory test was analysed by means of the X^2 analysis.

3. Results

3.1. NaCl Transference

A concentration of 10% NaCl in the brine increases ($p < 0.05$) the mass transfer in comparison to 5% NaCl. A higher concentration ($p < 0.05$) of salt was found inside the meat treated with 10% NaCl, both in the post-brining samples and in the post-smoking samples (Table 2). This is due to the higher availability of solutes in the solution. A significant effect ($p < 0.05$) of HIU was observed on the NaCl concentration in the post-brining samples. Ultrasonicated meat showed an increase of 24.76% in the amount of NaCl (0.61 to 0.81% without and with HIU, respectively). The effect of HIU on the salt content of the post-smoking samples was not significant ($p > 0.05$). The control samples had 0.86% of NaCl while the HIU samples had 0.98% of NaCl (Table 3).

Table 2. Effect of type of brining and salt concentration on the weight of meat, NaCl concentration, pH, water holding capacity (WHC) and shear force of pork *Longissimus dorsi* at post-brining process.

Factors	Weight, g	NaCl, %	pH	WHC, %
Brining type				
Static	83.15 ± 2.23^{b}	0.61 ± 0.17^{b}	5.90 ± 0.16^{a}	59.37 ± 2.81^{a}
HIU	86.54 ± 3.47^{a}	0.81 ± 0.23^{a}	5.91 ± 0.14^{a}	57.17 ± 3.78^{b}
NaCl				
5%	86.16 ± 2.67^{a}	0.54 ± 0.10^{b}	5.87 ± 0.13^{a}	58.24 ± 2.86^{a}
10%	85.58 ± 4.18^{a}	0.88 ± 0.16^{a}	5.94 ± 0.16^{a}	58.30 ± 4.06^{a}

HIU = high intensity ultrasound. WHC = water holding capacity, [a,b] Means with different literal within a factor denote significant difference ($p < 0.05$).

The increase of NaCl into the tissue may be attributed to the phenomenon of cavitation, micro-agitation and the formation of micro channels caused by HIU [5,7,13,24]. A low salt content in meat products is very important nowadays, since consumers are highly concerned about healthy and high-quality food.

Table 3. Effect of type of brining and salt concentration on the weight of meat, NaCl concentration, pH, water-holding capacity (WHC) and shear force of pork *Longissimus dorsi* following the post-smoking process.

Factors	Weight, g	NaCl, %	pH	WHC, %	SF, kg
Brining type					
Static	60.42 ± 3.71 [a]	0.86 ± 0.27 [a]	6.14 ± 0.23 [a]	82.18 ± 3.04 [a]	2.63 ± 0.50 [a]
HIU	63.06 ± 4.74 [a]	0.98 ± 0.34 [a]	6.16 ± 0.15 [a]	83.04 ± 3.80 [a]	2.42 ± 0.54 [a]
NaCl					
5%	86.16 ± 2.67 [a]	0.54 ± 0.10 [b]	5.87 ± 0.13 [a]	58.24 ± 2.86 [a]	2.65 ± 0.42 [a]
10%	85.58 ± 4.18 [a]	0.88 ± 0.16 [a]	5.94 ± 0.16 [a]	58.30 ± 4.06 [a]	2.40 ± 0.61 [a]

HIU = high-intensity ultrasound. WHC = water holding capacity, [a,b] Means with different letters within a factor denote significant difference ($p < 0.05$).

Normally, cured and smoked meats are characterized by a high content of sodium chloride (7% to 10%) [25]. Approximately 0.8% salt is required to maintain the technological characteristics of cured and smoked pork loin [26]. Low salt concentrations were achieved in this study, and these may be considered desirable amounts from health and quality perspectives. These results allow us to consider the HIU as a potential tool in the curing and smoking processes of reduced-sodium loin production.

3.2. Weight of Meat

The weight of the post-brining samples treated with HIU showed a significant increase ($p < 0.05$) compared to the control samples (Table 2). The initial weight of the samples increased by 2.47% after brining. However, the smoked samples did not show an effect ($p > 0.05$) from HIU application (Table 3). This lack of effect in the final smoked samples may be attributed to a weak binding of the brine to the tissue after curing and posterior liquid exudation caused by heat during smoking [27]. Cured and smoked meat usually has a typical weight loss of 26% to 35% after cooking or smoking [25]. In the present study, the samples evaluated in the post-smoking stage following the application of HIU had an average loss of 25.32% compared to their initial weight. Therefore, the weight loss in smoked pork after the effects of application is similar to the typical weight loss when the traditional smoking process is carried out.

3.3. pH

Treatment with HIU did not show any effect ($p > 0.05$) on the meta pH (Tables 2 and 3). These findings agree with McDonnell et al. [28], who also found no significant effects of HIU application (4.2, 9 and 11 W/cm^2) on the pH of *Longissimus thoracis et lumborum* of pigs. Similarly, Contreras-Lopez et al. [13] found no significant effect on the pH of the *Longissimuss lumborum* of pigs following the application of HIU (22 W/cm^2 for 30 and 90 min).

3.4. Water Holding Capacity (WHC)

The WHC in pork decreased significantly ($p < 0.05$) after the application of HIU in the post-brining samples. The control treatment had 59.37%, while the HIU-treated pork had 57.17% of WHC (Figure 3). These results differ from those reported by McDonnell et al. [28], who observed an increase in the water content of pork treated with 19 W/cm^2 for 10 or 25 min, and Siró [24], who reported that ultrasound-assisted brining results in significant increases in WHC, and this was higher with longer treatment durations (180 min).

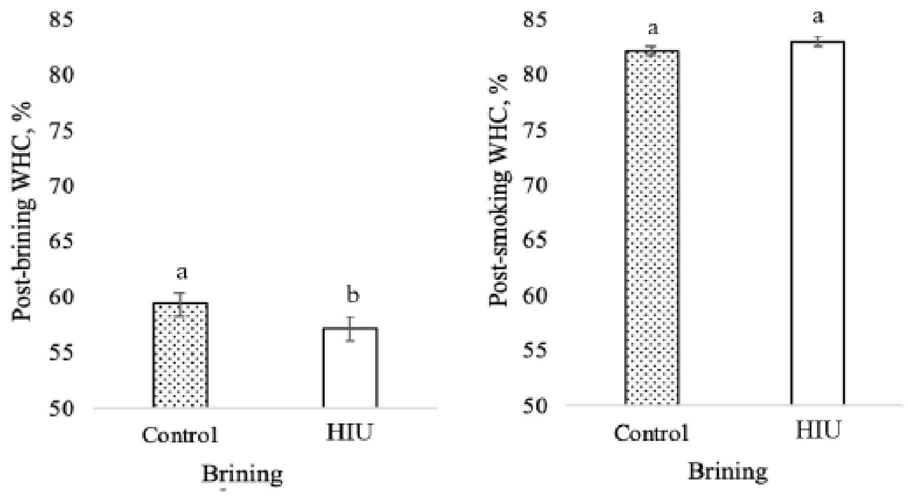

Figure 3. Effect of ultrasound-assisted brining on the post-brining and post-smoking WHC of pork *L. dorsi*. ^{a,b} Means with different letters denote significant difference($p < 0.05$).

On one side, the immersion of meat in brine with NaCl provokes muscle fibres to swell, and therefore its WHC increases [29]. Protein fibres can swell up to twice their size depending on the NaCl concentration. These ions tend to bind to the protein filaments of the meat and increase the electrostatic repulsion force among them. The swelling encourages a higher amount of side chains in proteins to bind water, which in turn improves WHC [30]. Therefore, if the HIU increases, then the amount of NaCl in the sample it would also increase its WHC. On the other side, analysis of water–protein interactions during HIU-assisted (19 W/cm^2 for 40 min) curing may be a surface phenomenon accelerating the mass transfer from brine to meat. This can denature proteins such as myosin [12,28].

In the present study, we hypothesized that the decrease of the WHC in sonicated meat could be caused by the denaturation of the proteins, reducing the swelling previously achieved by NaCl during curing. There was higher penetration of brine in the ultrasonicated samples, as evidenced by the increase in weight and the percentage of NaCl in the post-brining samples. However, the brine was probably not strongly bound to the structure due to protein denaturation. Further, liquid did not remain within the meat when exerting the mechanical pressure of the WHC analysis, yielding lower WHC percentages when HIU was used. The increase in weight observed in the sonicated post-brining samples was lost during cooking and smoking. Consequently, the WHC of the sonicated smoked meat did not show any significant difference ($p < 0.05$, 82.18% vs. 83.04% between the control and sonicated sample, respectively), although their values were higher than those post-brining (Table 2). Smoking dehydrates the meat, and afterwards, only the brine and the water that was strongly bound to the proteins will remain in the samples.

3.5. Shear Force

The type of brining (traditional or HIU) and the concentration of NaCl in the brine (5 or 10%) did not significantly affect the shear force of meat ($p > 0.05$). The SF values were 2.42 and 2.63 kgf for the sonicated and the control meat, respectively (Table 3). Regarding NaCl concentrations, SF values were 2.65 and 2.40 kgf for the 5% and 10%, respectively. Contrarily, Siró et al. [24] found a decrease in the toughness of the meat when low-intensity ultrasonication was applied for a long time (2.5–3 W/cm^2, 180 min). They reported that at higher intensities the HIU can increase the toughness of the meat due to the protein denaturation and loss of water-binding capacity. Ozuna et al. [5] observed a significant increase in the toughness of meat dur to HIU application. They attributed this effect mainly to the structural modifications of the proteins due to high concentrations of NaCl in the brine (up to 28%) and to the increase of NaCl in the sample due to the effects of HIU. They suggested that HIU increases the amount of NaCl in meat, and they observed that the higher the amount of NaCl, the higher shear force [5]. However, with the changes observed in the weight, NaCl content and WHC in samples from the present study, it is possible to infer that the migration of brine into the meat was not strongly linked to the structure of the meat. Moreover, the NaCl content in the samples was not high enough to produce any change in texture. These results could have a positive impact, because with the assistance of sonication, a reduced-sodium loin was obtained with no change to the WHC or shear force.

3.6. Colour

No colour coordinates were affected ($p > 0.05$) in post-brining samples due to the application of HIU (Table 4). These results agree with those found by McDonnell et al. [6] (10, 25 or 40 min; 4.2, 11 or 19 W/cm^2) and with Contreras-Lopez et al. [13] (22 W/cm^2 for 30 and 90 min) in pork. In contrast, the colour of bovine meat immersed in brine presents significant differences as a result of the application of HIU [31,32]. The colour of the meat is determined by the myoglobin protein, its quantity and chemical state and its combination with other substances such as oxygen, nitric oxide and nitrates [33]. Myoglobin is a globular haemoprotein, soluble in water and in dilute saline solutions [33]. As myoglobin is soluble in water, when meat is immersed in a water solution, myoglobin dilution takes place. The myoglobin content varies among animal species. Beef contains 0.3–1% and pork 0.04–0.06% [34]. This could explain why beef presents higher changes in colour when immersed and sonicated compared to pork. On the other hand, the colour coordinates (a*, b*, chroma, and hue angle) in smoked samples were affected by the application of HIU ($p < 0.05$). The samples treated with HIU were less red (12.43 ± 2.37) than the control samples (15.41 ± 1.81) (Table 5).

Table 4. Effect of the type of brining and the salt concentration on the meat colour of pork *Longissimus dorsi* following the post-brining process.

Factors	L*	a*	b*	Chroma	Hue
Brining type					
Static	51.67 ± 3.81 ^{a}	15.41 ± 1.81 ^{a}	14.99 ± 2.03 ^{b}	22.21 ± 2.59 ^{a}	44.52 ± 5.91 ^{b}
HIU	50.29 ± 2.13 ^{a}	12.43 ± 2.37 ^{b}	16.08 ± 2.36 ^{a}	20.47 ± 2.24 ^{b}	52.29 ± 6.94 ^{a}
NaCl					
5%	51.28 ± 3.15 ^{a}	14.28 ± 2.49 ^{a}	15.15 ± 1.93 ^{a}	21.44 ± 3.17 ^{a}	46.81 ± 6.37 ^{a}
10%	65.67 ± 3.15 ^{a}	13.56 ± 2.67 ^{a}	15.93 ± 2.50 ^{a}	21.25 ± 1.79 ^{a}	50.28 ± 8.32 ^{a}

HIU = high-intensity ultrasound. WHC = water-holding capacity, ^{a,b} Means with different letters within a factor denote significant difference ($p < 0.05$).

Table 5. Effect of the type of brining and the salt concentration on the meat colour of pork *Longissimus dorsi* following the post-smoking process.

Factors	L*	a*	b*	Chroma	Hue
Brining type					
Static	47.56 ± 3.75 ^{a}	6.38 ± 1.50 ^{a}	5.25 ± 1.60 ^{a}	8.30 ± 2.00 ^{a}	39.27 ± 5.90 ^{a}
HIU	46.55 ± 3.25 ^{a}	5.80 ± 1.44 ^{a}	4.31 ± 1.59 ^{a}	7.27 ± 1.99 ^{a}	35.83 ± 6.74 ^{a}
NaCl					
5%	47.79 ± 3.60 ^{a}	6.24 ± 1.37 ^{a}	5.20 ± 1.77 ^{a}	8.18 ± 2.01 ^{a}	39.10 ± 7.16 ^{a}
10%	46.33 ± 3.32 ^{a}	5.93 ± 1.61 ^{a}	4.37 ± 1.44 ^{b}	7.39 ± 2.03 ^{a}	36.12 ± 5.54 ^{b}

HIU = high-intensity ultrasound. WHC = water-holding capacity, ^{a,b} Means with different letters within a factor denote significant difference ($p < 0.05$).

A significant interaction ($p < 0.05$) between the HIU treatment and the NaCl concentration was found on hue value. The hue angle increased significantly ($p < 0.05$) in ultrasonicated meat cured in 10% NaCl brine. In general, a hue value close to 60 would indicate a red–yellow hue, and one close to 30 would indicate a red–pink hue [28]. Therefore, ultrasonicated meat cured in 10% salt had a more yellow tone than the other samples

(Figure 4). Hue changes in meat are due to variations in a* and b*; in this regard, HIU-treated samples were more yellow, and less red. Similar observations occurred in the saturation (C*) of the colour—the samples treated with HIU showed a significantly lower saturation ($p < 0.05$) than that of traditional brined meat. This means that the colour of sonicated pork is less intense than that of non-sonicated samples. Ultrasound-assisted curing allows the meat to retain more water, but part of it is lost after cooking and smoking, giving rise to a potential change in the colour of the end-product.

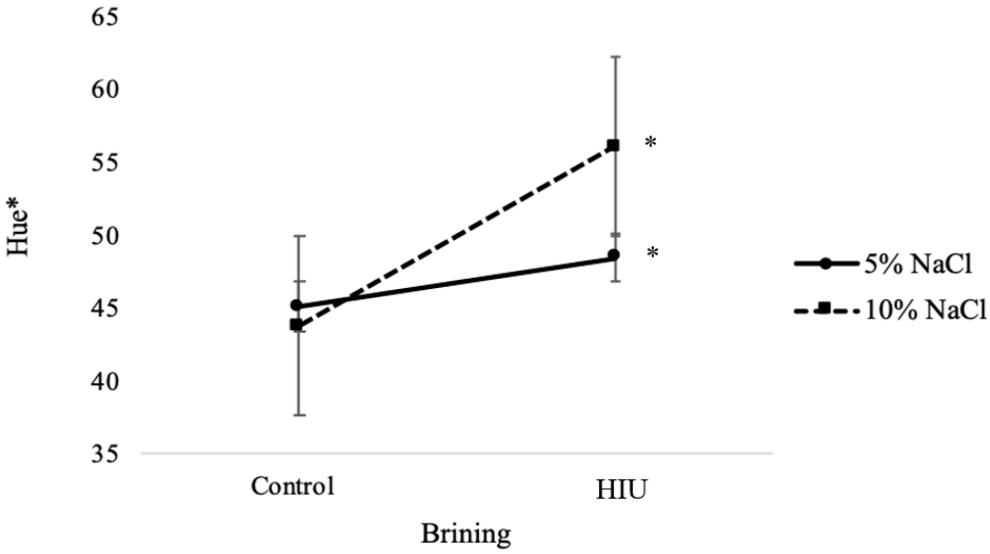

Figure 4. Effect of the interaction of HIU and NaCl concentration on the hue angle of *L. dorsi* from cured and smoked pork. * Indicates significant difference between treatments ($p < 0.05$).

3.7. Sensory Analysis

Meat samples with HIU-assisted brining were significantly ($p < 0.05$) less preferred by consumers due to their appearance (Figure 5). This is possibly due to the variations in colour, particularly an increase of yellow tones (Hue) provoked by ultrasonication and high NaCl concentration. According to Cornforth [35], colour is the main criterion that consumers take to evaluate the quality and acceptability of meat. Pink colourations are the preferred in cured pork. Thus, colour is one of the main attributes that influence the consumer's purchase decision. In the present study, consumers perceived that sonicated samples were more yellow and less pink, and therefore they preferred the control samples which were perceived to be pinker. Flavour and texture characteristics were not significantly affected ($p > 0.05$) by treatments. These findings agree with the physicochemical results, according to which no effect of HIU was observed in the shear force nor in the NaCl content of the smoked meat.

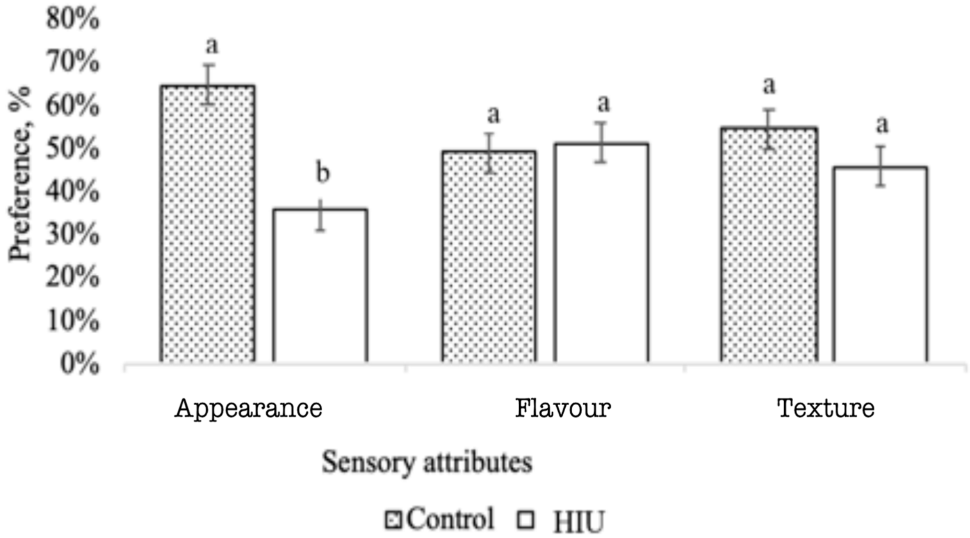

Figure 5. Effect of ultrasound-assisted brining (HIU, 106 W/cm^2) on the consumer preference of the appearance, flavour, and texture of smoked pork loin. ^{a,b} Means with different letters denote significant difference between treatments ($p < 0.05$).

4. Conclusions

The use of HIU-assisted brining was an efficient method to reach 0.8% NaCl in the smoked pork loin without a negative impact on the meat technological quality. This information may help in considering the use of HIU as a tool in the curing and smoking processes of reduced-sodium pork production. Ultrasonication did not change the weight of the end-smoked product. Ultrasonicated meat showed higher weight and higher WHC than non-sonicated meat after brining, but these gains were lost after smoking. Additionally, the ultrasonicated meat showed a higher yellow and lower red colour, this being a less intense colour than traditionally cured meat. Consumers preferred the appearance of the traditionally cured and smoked meat. The HIU-assisted brining did not change the WHC or shear force of cured pork, and it produced only a slight change in colour intensity. It is recommended to carry out more research with reduced-sodium smoked products, including sensory analysis, in order to establish the ideal conditions of ultrasound application for potential application into the industry of smoked meat products.

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