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Effects of Ultrasound Pretreatment and Ageing Processing on Quality and Tenderness of Pork Loin

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Abstract Tenderness is a primary indicator of meat quality, which directly influences consumer acceptance of the meat. Ultrasound can effectively increase the tenderness of red meat, such as pork and beef, by breaking up muscle fibers and connective tissues through mechanical force, thus making it a basis for physical tenderization of meat to improve meat quality. In this study, ultrasound (2200 W, 15 kHz) was applied in the processing of pork loin to explore the influences of varying treatment durations (0-6 minutes) and posttreatment aging durations (0-2 days) on the tenderness, texture profile, physical and chemical qualities (myofibrillar fragmentation index, or MFI, and rate of marinade absorption), and sensory evaluation (9-point hedonic scale) of meat. The results indicated that ultrasonic treatment (2200 W) for 6 minutes can effectively tenderize the meat by increasing the MFI to 15.1%, lowering the hardness in texture profile analysis (TPA) to 87.6%, and reducing shear force to 87.9%. Moreover, if pork loin is allowed to age for 48 hours following 6 minutes of ultrasonic treatment, shear force can be further reduced to 72.3%. The sensory evaluation scores for texture, tenderness, and overall acceptance of pork loin increased with the elongated ultrasonic treatment.

Keywords: *meat product, physical tenderization, texture, shear force, cooking loss, sensory*

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1. Introduction

Pork is one of the farming and animal products that have the highest output value in Chinese communities; Taiwan particularly, the butchery industry reached NT$78.1 billion worth of annual output in 2014, and the meat processing industry NT$29.3 billion [1]. Economic growth in modern times has substantially increased the demand for quality meat, with special emphasis on the tenderness, juiciness, and flavor. Tenderness, in particular, is one of the primary indicators consumers use to rate meat quality [2] because it directly affects their sensory evaluation, and thus acceptance of the meat [3]. The primary factor that influences meat tenderness is the elastin content, which causes the meat to contract when heated and thus become harder. Thus, the meat containing the elastin-rich connective tissues is harder and thereby receives lower consumer acceptance and is sold at a lower price. Therefore, the tenderness of meat and the processing techniques to improve meat quality are considered the key factors influencing the economic value of meat products [4]. After slaughter, meat must generally undergo resolution of rigor and aging following autolysis before it reaches the desired tenderness, which is caused by the protease in the meat that can hydrolyze actin and myosin in myofibrils as well as the proteins and connective tissue compounds in the cytoskeleton [5,6]. The duration for these processes can vary depending on the type of meat; for example, beef requires days, whereas chicken requires only hours. However, they incur considerable extra costs to meat processing plants, particularly in labor costs, space and equipment for cold storage, and the loss caused by dehydration [7]. These give rise to techniues for greater tenderness or shorter aging duration, primarily through the degradation or breakdown of elastin and myofibrils into smaller pieces. The meat process industry has adopted various physical, chemical, and enzymatic approaches for improved tenderization of meat [3,8]. The physical approach involves mechanical tenderizing that relies on mechanical forces (needle/ blade tenderization, rolling, and tumbling) to break up connective tissues and achieve tenderization. This approach facilitates the control of tenderization degree without compromising the meat flavor; however, it takes a longer duration, which can result in changes in the product's form or quality, microbial contamination at spots of physical damage, and the loss of salt-soluble protein [9,10,11]. The chemical approach relies on salts, which are added through curing or injection, to facilitate the release of salt-soluble protein, increase water holding capacity (WHC), reduce hardness, and enhance shelf life, flavor, juiciness, texture, and yield of product [12,13]. However, curing is often such a long and slow process that it can cause an increase in time costs, energy consumption, and undesirable microbial growth [12,14]. The enzymatic approach achieves meat tenderization through additive proteolytic enzymes, which break up elastin, collagen, myofibrils, and connective tissues. However, its mechanism is difficult to control, and the additives are costly and can easily cause a change in flavor. The desire for a quicker and more effective tenderizing method has inspired researchers to propose numerous techniques, such as marination, aging, conditioning, electrical stimulation, wing restraints, pressure-heat treatment, shock waves [7,10,15], and some relatively novel techniques, such as using hydrostatic pressure [16] or ultrasound [17,18,19].

Ultrasonic treatment (15-100 kHz) is a new processing technique that uses ultrasound to pass through liquid and generate cavitation bubbles, which can be characterized by the dynamics of oscillations (repeated compression and decompression) and the maximum temperature and pressure (35-120 MPa) reached when they collapse [15,20,21]. It chiefly relies on high-speed mechanical movements and cavitation in liquid to create massive physical forces (e.g. in the forms of shock waves or shear forces) that can break down organic tissues and improve food quality [22,23]. Ultrasound travels through the water and objectsthat are a mechanical impedance match to the water, meat is made up of approximately 75% water, the ultrasound also pass through muscle and ruptures selected cellular components [15,24,25]. Ultrasonic treatment has the advantages of being highly efficient, instantaneous, inexpensive, and nondestructive and also because it adds value to cheaper foods, it is primarily applied to improving food texture and quality [24,26]. Its application in meat processing facilitates rapid marination [14,27] and improved tenderness of red meat, such as beef [15,17,23], pork [10], and mutton [28], as well as the tenderness of deboned chicken breasts [7]. Research has asserted that the high effectiveness of ultrasonic treatment for meat tenderization and the convenience of applying it on packaged products make it a highly promising technique [26].

Few studies have investigated applying ultrasonic treatment to pork or integrating an aging process that involves cold-storage curing. Therefore, this study directed ultrasonic energy into pork loin to explore how the power intensity of ultrasonic treatment, treatment duration, and aging duration affects the texture, tenderness, and sensory evaluation of pork loin to enhance meat quality, improve consumer selectivity and convenience, and accelerate tenderizing technique development in the meat processing industry.

2. Materials and Methods

2.1. Preparation of Pork Loin

Each pork loin (Cha I Shan Foods Co., Ltd, Taiwan) were maintained 20 h at 0°C and they were cut into blocks (100 mm x 50 mm x 10 mm, length, width and height, respectively). The weights of all the individual samples were recorded before the ultrasound treatment. The individual samples were mixed with 5.0% soy sauce (14.5% salt, Wan Ja Shan Co., Ltd, Taiwan), 1.5% sugar (99.5%, Taiwan Sugar Co., Taiwan), 1.5% spices (Tomax Enterprise Co., Ltd, Taiwan) and 35% water, it were vacuum-packed in plastic bags (NY / LLDPE laminated film) and stored at 5°C until used for ultrasonic treatment.

2.2. Ultrasound Treatment

Each of the samples was randomly allocated to ultrasound treatment and ageing treatments. The ultrasound treatment was performed by an ultrasound probe (FRONTXIN Ultrasonic Technology Co., Ltd, Taiwan). The maximum power of the equipment was 2200 W, operating frequency was set to 15 kHz and the active surface of the head was 78.5 cm^2. The vacuum packed sample were treated in a cooling water tank (15 L) filled with water by an ultrasound head fixed horizontally at 10 cm from the samples, so there was no direct contact between the samples and the sonotrode. Ultrasonice head was fully immersed in the water. The samples exposed to ultrasound (power density was 0.14 W / g) for different periods of time (0, 0.5, 1, 2, 3, 4, 6 min). The ultrasound treatment was performed at 0°C and treated for 1 min before rested 0.5 min of cycling. After ultrasound treatment, the sample were aged at 4°C for different periods of time (0, 1 and 2 days).

2.3. Myofibril Fragmentation Index (MFI) of Pork Loin

The MFI method used was that of the classic turbidity method described by [29] with modifications according to [30]. The protein concentration of the myofibril suspension was determined in duplicate using the Biuret reaction [31] with a standard curve from 0 to 5 mg / mL BSA. Aliquots of the myofibril suspension were then diluted in buffer to a final protein concentration of 0.5 mg / mL in triplicate. The diluted protein was immediately poured into a quartz cuvette and the absorbance measured at 540 nm with a spectrophotometer(EPOCH 2, BioTek, USA). The mean of the triplicate absorbance readings was multiplied by 200 to give the MFI.

2.4. Marinade Absorption Rate of Pork Loin

The weight of each pork loin samples were recorded immediately after ultrasonic treatment, the samples were taken from the vacuum bags, blotted dry and weighed. Marinade absorption rate was calculated as:

$$\text{Marinade absorption rate } (\%) = \frac{\text{After ultrasonic weight} - \text{Initial weight}}{\text{Initial weight x100}}.$$

2.5. Texture Profile Analyses of Pork Loin

The pork loin samples were cooked in a boiling water to an internal temperature of 72°C, and then remove the package and sauce, cooled to room temperature. The texture profile analyses (TPA) indices of pork loin samples were determined using a texture analyzer (Model TA-XT2 Texture Analysis, England). The conditions of texture analyzer were modified by [32]. Pre-test speed: 2.0 mm / s; test speed: 1.0 mm / s; post-test speed: 1.0 mm / s; distance: 5.0 mm; time: 5.0 s; trigger type: auto; and trigger force, 10 g.

2.6. Shear Force of Pork Loin

The pork loin samples were cooked in a boiling water to an internal temperature of 72°C, and then remove the package and sauce, cooled to room temperature. Two strips (10 mm x 10 mm x 100 mm) parallel to the longitudinal orientation of the muscle fibers were taken from each pork loin sample. The shear force indices of pork loin samples were determined using a texture analyzer (Model TA-XT2 Texture Analysis, England). The conditions of texture analyzer were modified by [33]. The test compression load transducer and the crosshead speed were set at 5 kg and 2 mm / s. The peak force (N) was the maximum value when the strip cut across the direction of the fibers using a texture analyzer.

2.7. Sensory Analysis

The sensory analysis of pork loin samples were evaluated by 30 untrained assessors selected according to their habits. Samples were labeled with 3-digit random numbers and served in random order to assessor in individual booths. Assessors were instructed to cleanse their palates with water between samples. A hedonic test was carried out using 9 point scales (9 = like extremely and 1 = dislike extremely) in which the assessors evaluated different attributes: appearance, flavour, texture, tenderness, overall acceptability [34].

2.8. Statistical Analysis

Data were analyzed using SPSS 12.0 for one-way ANOVA. Duncan's new multiple range test was used to resolve the difference among treatment means. A value of $p < 0.05$ was used to indicate significant difference.

3. Results and Discussion

3.1. Myofibril Fragmentation Index and Marinade Absorption Rate of Pork Loin on Ultrasound Treatment

Numerous studies have concluded that the purpose of fowl meat tenderization is to break down the myofibrillar structure [35,36], the degree of which can be represented using the MFI. Accordingly, the MFI can serve as a preliminary indicator for meat product tenderization [29,37]. Figure 1 shows the MFI of pork loin after undergoing varying intensities of ultrasonic treatment (300 W, 2200 W). The results reveal that the MFI rose substantially from 33.2 to 37.7 after 30 minutes of ultrasonic treatment at 300 W, and when the power intensity was raised to 2200 W, the MFI took only 4 minutes to rise considerably from 44.9 to 54.3. This is evidence that high-intensity ultrasonic treatment exerts enough energy to break down myofibrils, which also suggests its potential of tenderization. According to [18], the MFI of beef rises considerably when subjected to 20 kHz of ultrasonic treatment, and the rise is positively correlated with power intensity (150-300 W) and treatment duration (30-120 minutes); furthermore, they observed that the ultrasonic energies that they applied were sufficiently high to degrade desmin around the Z-disk of the sarcomere and sarcolemma, resulting in the breakdown and fragmentation of myofibrils. [10] reported that the cavitation induced by ultrasound could break down the Z-line in pork loin, which echoes the observation of [15] that high-frequency (2.6 MHz) and high-power (10 W / cm^2) ultrasound can break down the Z-line for the tenderization of bovine *Semimembranosus* muscles. The connection between the Z-line and A-band or I-band is associated with the breakage of sarcomeres; Z-line is the link between myofibrils, its breakage signifies the fragmentation or shortening of muscle fibers, which contributes to meat tenderization [38]. WHC is another primary indicator of meat quality because it is related to the juiciness, texture, and flavor in sensory evaluation [39]. In view of the aforementioned myofibril-breaking ability of ultrasound, measuring the rate of marinade absorption to determine the amount of marinade required is a method of improving the flavor, texture, tenderness, and juiciness of meat products. The results for the rate of marinade absorption were as shown in Figure 2, which indicates that when ultrasonic treatment at 300 W was applied for 30 minutes, the rate of marinade absorption rose significantly from 6.6% to 9.6%. Furthermore, when the power was raised to 2200 W, the rate of marinade absorption also rose as the treatment duration was extended. It showed a significant rise in only 4 minutes, and when the treatment was extended to 6 minutes, the rate had risen from 6.6% to 12.8%. [23] determined that introducing ultrasonic treatment in marination could effectively increase the osmosis of salts in the marinade into beef with either a rise of power intensity (2.39-20.96 W / cm^2) or an extension of treatment duration (30 - 120 minutes). Both [14] and [27] determined that ultrasound can accelerate the osmosis of salts during marination, the trend of which corroborates the results of the present study. Numerous studies on meat from different body parts have suggested that ultrasonic treatment correlates positively with the rate of marinade absorption [40,41,42,43]. [10] suggested that, during the marination of pork loin, the application of a low-frequency (20 kHz) and low-power (2.5 W / cm^2) ultrasonic treatment increases the interval between myofibrils to allow more space for water uptake, causing a significant increase in muscle water-binding capacity that in turn contributes to greater meat tenderness. Another study asserted that the cavitation effect induced through ultrasound can be used to modify cell membranes, creating micro-channels and micro-stirting that facilitate the mass transport of marinade and change of meat structure or texture [44,45]. In the present study, the rate of marinade absorption was determined to coincide with the rise of MFI, inferring that the breakage of myofibrils represents damage to meat microstructures, which can promote marinade absorption. Additionally, the release of salt-soluble protein (e.g. myosin) in the meat also increased after the damage to the meat microstructures, and thus contributes to the increase WHC of meat [46]; [39] Research has also indicated that both modifying protein structures and degrading (i.e. breakage) myofibrils can enhance WHC of meat, and the WHC influences product appearance and juiciness; therefore, WHC is a critical economic indicator for meat processing [47].

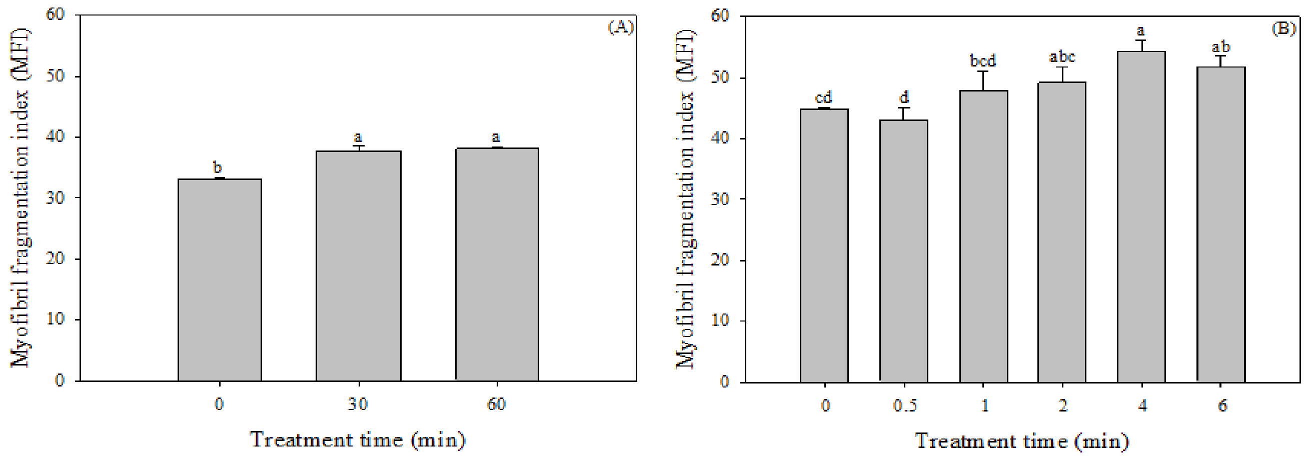

Figure 1. Effect of Ultrasound Treatment (a) 300 W and (b) 2200 W on MFI of Pork Loin (Mean ± SD, n = 3)

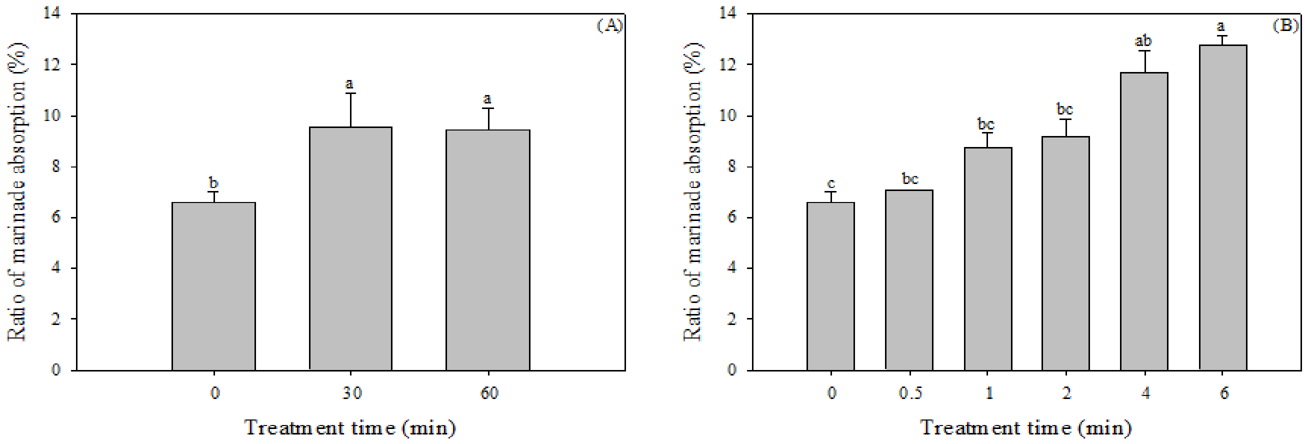

Figure 2. Effect of Ultrasound Treatment (a) 300 W and (b) 2200 W on Ratio of Marinade Absorption in Pork Loin (Mean ± SD, n = 3)

3.2. Texture Properties and Tenderness of Pork Loin on Ultrasound Treatment

The hardness and tenderness of meat products are the most decisive sensory characteristics in consumers' evaluation of meat quality [2]. Technically, tenderness can be represented by two primary indicators, hardness and shear force: Hardness is measured using a circular probe that compresses meat to simulate the chewing action, whereas shear is measured using a blade-like probe on meat tosimulate the cutting action of the incisors. Table 1 shows the TPA results of pork loin treated with various intensities of ultrasound. It indicates that after 30 minutes of ultrasonic treatment at 300 W, the hardness of pork loin dropped substantially from 254 g to 218 g, and when the treatment was intensified to 2200 W, the hardness dropped to 210 g in just 2 minutes. [10] noticed a similar trend in their experiment, and they concluded that the hardness of pork decreases with the increase in ultrasonic intensity or treatment duration, but excessive intensity (4 W / cm^2) or treatment duration can result in protein denaturation, which causes hardness to increase to some extent, yet not as high as the untreated specimen in static brining. [48] suggested that submerging meat specimen in a warm water bath while applying ultrasonic treatment can prevent the hardening of meat or loss of WHC caused by the heat denaturation of protein. Because the cavitation effect induced by ultrasound and the vibration of ultrasound itself can physically weaken the structure of foods, they can be inferred to be the mechanism for ultrasound to reduce the hardness of meat [15,17,49]. Figure 3 shows the shear of pork loin after ultrasonic treatment. Shear force was reduced after ultrasonic treatment at 300 W and 2200 W, but at 300 W shear force dropped to 92.7% after 60 minutes, which is not a significant drop compared with the control group; by contrast, at 2200 W, it dropped to 90.7%, significantly lower than the control group, in just 4 minutes, and after 6 minutes it had further dropped to 87.9%. [17] applied ultrasonic treatment (24 kHz, 12 W / cm^2) to beef (*Longissimus lumborum* and *Semitendinosus*) for 2-4 minutes, and determined that it effectively reduced the shear force and hardness of the meat, echoing the finding of [35] that exposure to ultrasound can improve beef tenderness (*Longissimus lumborum* and *Semitendinosus*). [50] determined that high-intensity ultrasound (40 kHz, 2400 W) can reduce the shear force of packaged chicken breasts. [18] determined that beef took 120 minutes to be significantly tenderized when treated by ultrasound (20 kHz) at a lower intensity of 200 W, but when the intensity was raised to 250 W, the duration was shortened to 30 minutes. Therefore, ultrasound can be concluded to require a shorter duration to tenderize meat when its intensity is high. Moreover, the degree of tenderization appears to be in accordance with the MFI, which suggests that shear reduction relates to the myofibrils fragmentation. In the present study, the results of the shear force test were also determined to be in accordance with the MFI results.

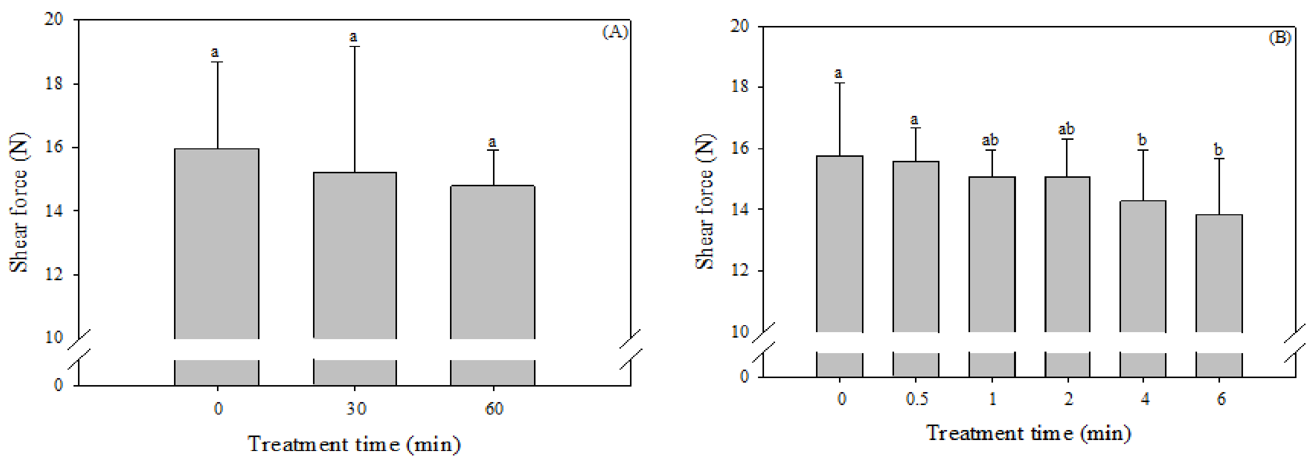

Figure 3. Effect of Ultrasound Treatment (a) 300 W and (b) 2200 W on Shear Force of Pork Loin (Mean ± SD, n = 10)

Table 1. Effect of Ultrasound Treatment on Texture Properties (TPA) of Pork Loin (Mean ± SD, n = 10)

Treatment	Time (min)	Hardness (g)	Springiness	Cohesiveness	Gumminess (g)	Chewiness(g)
Control	0	254.3 ± 28.4^{a}	0.870 ± 0.014^{abc}	0.710 ± 0.013^{c}	156.4 ± 18.8^{ab}	147.2 ± 17.7^{a}
US-300W	30	218.1 ± 17.9^{bc}	0.845 ± 0.018^{b}	0.700 ± 0.008^{c}	154.9 ± 19.9^{a}	136.5 ± 19.4^{a}
US-300W	60	214.8 ± 14.8^{bc}	0.853 ± 0.014^{b}	0.719 ± 0.007^{a}	151.4 ± 13.1^{a}	136.5 ± 15.5^{a}
US-2200W	0.5	238.6 ± 17.7^{ab}	0.873 ± 0.020^{ab}	0.713 ± 0.013^{c}	153.9 ± 15.1^{b}	145.0 ± 13.1^{a}
US-2200W	1	240.4 ± 23.4^{ab}	0.854 ± 0.019^{c}	0.713 ± 0.013^{c}	160.6 ± 23.8^{ab}	148.6 ± 20.5^{a}
US-2200W	2	210.4 ± 23.1^{c}	0.862 ± 0.032^{abc}	0.730 ± 0.018^{b}	157.8 ± 21.2^{ab}	134.0 ± 19.1^{a}
US-2200W	4	213.5 ± 35.6^{c}	0.859 ± 0.028^{bc}	0.732 ± 0.021^{b}	158.9 ± 27.3^{ab}	137.0 ± 31.4^{a}
US-2200W	6	222.8 ± 13.9^{bc}	0.876 ± 0.012^{a}	0.748 ± 0.016^{a}	171.4 ± 17.0^{a}	148.9 ± 12.5^{a}

Means with different superscript letters within the same column are significantly different at $p < 0.05$.
*Control: without ultrasound treatment, **US-300W: ultrasound treatment at 300 W, ***US-2200W: ultrasound treatment at 2200 W

Table 2. Effect of Ultrasound Treatment Sensory Analysis on Shear Force of Pork Loin (Mean ± SD, n = 30)

Treatment	Time (min)	Appearance	Flavour	Texture	Tenderness	Overall
Control	0	6.63 ± 1.43^{a}	6.07 ± 1.01^{a}	6.07 ± 1.17^{a}	4.70 ± 1.47^{d}	6.10 ± 1.16^{ab}
US-300W	30	6.50 ± 1.14^{a}	6.40 ± 0.50^{a}	6.30 ± 1.02^{a}	4.90 ± 1.54^{cd}	6.40 ± 0.81^{a}
US-300W	60	6.60 ± 1.71^{a}	6.40 ± 1.04^{a}	6.00 ± 1.20^{a}	5.50 ± 1.31^{bc}	6.10 ± 1.40^{ab}
US-2200W	2	7.10 ± 1.06^{a}	6.00 ± 0.64^{a}	6.30 ± 0.65^{a}	5.20 ± 1.10^{bcd}	5.67 ± 0.79^{b}
US-2200W	4	6.90 ± 1.24^{a}	6.10 ± 0.71^{a}	6.20 ± 1.19^{a}	5.90 ± 1.47^{ab}	6.00 ± 1.20^{ab}
US-2200W	6	6.60 ± 1.30^{a}	6.40 ± 1.22^{a}	5.90 ± 0.84^{a}	6.20 ± 1.63^{a}	6.44 ± 1.12^{a}

Means with different superscript letters within the same column are significantly different at $p < 0.05$.
*Control: without ultrasound treatment, **US-300W: ultrasound treatment at 300 W, ***US-2200W: ultrasound treatment at 2200 W

3.3. Sensory of Pork Loin on Ultrasound Treatment

Because TPA can only be used to judge the hardness and shear force of food through monotonous compressing and cutting actions, it cannot fully represent the texture of meat products. Therefore, it must be augmented by sensory evaluation, in which tenderness is the chief indicator of consumer satisfaction with meat [15]. In the sensory evaluation, pork loins treated with varying intensities of ultrasound were water-cooked until they reached an internal temperature of 72°C, and then they had their appearance, flavor, texture, tenderness and overall acceptability evaluated. The results were as shown in Table 2. In terms of appearance, the differences between the experimental groups and control group were nonsignificant, and the brightness and redness of the experimental groups were 49.65-52.82 and 4.28-6.30 (data not shown), respectively; not sufficient to influence the testers' preferences. [17] reported that ultrasonic treatment did not affect the hue of beef, and [51] similarly determined that hydrodynamic shockwaves (similar to ultrasonic) have little effect on the hue of chicken, regardless of whether it is applied when the meat is fresh or after it has been stored awhile and whether the meat is cooked or raw. In terms of tenderness, the scores for treated specimens were significantly higher, and they tended to rise with the extension of treatment duration; ultrasonic treatment at 300 W required 60 minutes for the tenderness to become significantly greater than that of the control group (from 4.7 points to 5.5 points), but at 2200 W only 4 minutes were required to make testers sense a difference (from 4.7 points to 5.9 points, significantly higher than the control group; the score even reached 6.2 points after 6 minutes). Apparently, high-powered ultrasonic treatment can quickly attain the desired tenderness, which is more or less in accordance with the aforementioned MFI and shear results; hence, the rise in MFI and the decrease in hardness and shear can all reflect the actual sensory experience of the meat. Unlike other processing methods, the fact that ultrasound can improve the tenderness of meat without altering its appearance prevents the risk of altering the appearance, form, or color of meat products beyond consumers' stereotypical impression of meat.

3.4. Shear Force and Tenderness of Pork Loin on Ultrasound and Aging Treatment

The breakage and fragmentation of muscle fibers can be considered from two aspects: first, ultrasonic energy passing in water forces meat to vibrate, which, along with the cavitation effect that induces shear forces, cause damage to the microstructure in the meat [38,52]. Second, either that the mitochondrions and sarcolemma in muscle cells are damaged by ultrasound and release Ca^{2+} cations that activate calpain [53,54] or cell structures (e.g. lysosomes) are damaged to release their protease [17,35,52,53]; both eventually lead to the degradation of myofibrillar protein and connective tissues and thus the tenderization of meat. In the present study, specimens of pork loin were subjected to 2200 W of ultrasonic treatment for 0, 3, and 6 minutes to break up the muscle tissues, then marinated and aged for 0, 24, and 48 hours to further enhance their tenderness. Results of their shear analysis were as shown in Figure 4: For the groups without ultrasonic treatment, 24-48 hours of aging did not cause any significant decrease in shear. For the groups that have been treated for 3 and 6 minutes, their shear values both significantly dropped after aging for 48 hours compared with non-aging (0 hour). Moreover, the group that was treated for 3 minutes exhibited no sign of tenderization before aging, but once aged its shear force became lower than that of the group that was untreated but aged for 24 hours; by contrast, the groups that were treated for 6 minutes appeared to be tenderized both before and after aging, particularly the one that was aged for 48 hours, whose shear was reduced to 72% of that of the untreated control group. [17] reported that ultrasonic treatment (24 kHz, 12 W / cm^2) for 2-4 minutes could effectively reduce the hardness of beef and raise its tenderness; when the meat was further aged for 1-8.5 days at 5°C, the reduction in shear force and hardness was most significant during day 1, but after day 3, the effect became negligible. [51] indicated that the tenderizing effect of hydrodynamic shockwaves (similar to ultrasonic) is not necessarily instantaneous on chicken, but after being in storage for some time the meat's shear exhibits a decreasing tendency. [19] studied chicken that was subjected to ultrasonic treatment (24 kHz, 12 W / cm^2) for 4 minutes and then placed in cold storage at 4°C to age for 1 day and determined that the endogenous proteolytic enzyme could effectively improve the tenderness of the meat. The mechanism for this phenomenon is probably the same as the aforementioned effect of ultrasonic treatment enhancing the release and activity of protease, thus facilitating the improvement in tenderness after storage. The effect of ultrasound on the tenderization and aging of meat products has been proven to be achieved through the damage of lysosomes in muscle cells for the release of cathepsin, as well as the release of Ca^{2+} cations, for the physical damage of muscle tissues [15,19,26]. Further sensory evaluation results were as shown in Table 3, which suggests that the experimental groups exhibited little difference in appearance, flavor, and texture. However, in terms of tenderness, the groups that were subjected to ultrasonic treatment for 6 minutes (and then either aged for 24-48 hours or not aged) exhibited greater tenderness than the untreated groups, and the highest tenderness score was as high as 6.4 points. These results suggest that ultrasonic treatment is effective in tenderizing pork loin and help enhance its curing. Moreover, tenderization can be further improved through marination and aging. Because ultrasonic treatment has the added advantage of not causing negative effects to meat products, such as drastic changes in the quality (color, texture, cooked loss, and juiciness), sensory characteristics, and oxidation stability, or causing microbial contamination [55,56], it is a novel approach that is believed to be promising.

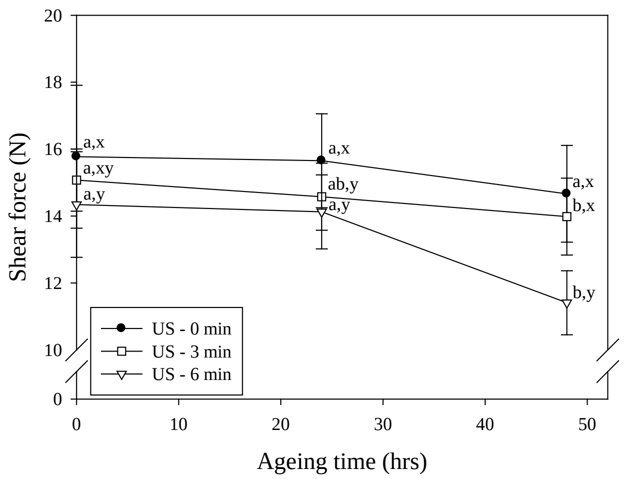

Figure 4. Effect of Ultrasound Treatment(2200 W) Time on Shear Force of Pork Loin during Ageing Processing. ●: without ultrasound treatment, □: ultrasound treatment for 3 min, ▽: ultrasound treatment for 3 min. (Mean ± SD, n = 10)

Table 3. Effect of Ultrasound Treatment(2200 W) and Aging on Sensory Evalutaion of Pork Loin. (Mean ± SD, n = 10)

Ultrasound time (min)	Aging time (hr)	Appearance	Flavour	Texture	Tenderness	Overall
0	0	6.40 ± 1.65^{a}	5.90 ± 1.06^{a}	6.11 ± 0.87^{a}	5.00 ± 1.76^{d}	5.60 ± 0.81^{b}
0	24	7.00 ± 1.02^{a}	6.00 ± 0.45^{a}	5.78 ± 1.13^{a}	4.60 ± 1.04^{cd}	6.00 ± 1.20^{ab}
0	48	6.60 ± 1.30^{a}	6.40 ± 1.22^{a}	6.11 ± 1.20^{a}	5.30 ± 0.92^{bc}	6.50 ± 1.14^{a}
3	0	6.40 ± 1.52^{a}	6.30 ± 0.79^{a}	5.90 ± 0.57^{a}	5.70 ± 0.65^{ab}	6.30 ± 1.29^{a}
3	24	6.50 ± 0.68^{a}	6.20 ± 1.10^{a}	5.60 ± 1.51^{a}	5.40 ± 0.93^{bc}	6.20 ± 1.42^{a}
3	48	6.70 ± 0.79^{a}	6.40 ± 0.81^{a}	6.00 ± 1.63^{a}	5.90 ± 1.67^{ab}	6.00 ± 1.64^{a}
6	0	6.60 ± 1.30^{a}	6.40 ± 0.93^{a}	5.90 ± 0.88^{a}	6.40 ± 1.22^{a}	6.30 ± 1.02^{a}
6	24	6.30 ± 0.92^{a}	6.10 ± 1.16^{a}	6.00 ± 0.82^{a}	6.00 ± 1.11^{ab}	6.10 ± 1.06^{a}
6	48	6.50 ± 0.82^{a}	6.40 ± 1.04^{a}	6.30 ± 1.16^{a}	6.30 ± 1.44^{a}	6.30 ± 1.21^{a}

Means with different superscript letters within the same column are significantly different at $p < 0.05$.

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