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APPLICATION OF ACTIVE ULTRASOUND IN MEAT BRINING TECHNOLOGY

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1. INTRODUCTION AND OBJECTIVES

Foods of animal origin are nutrient-rich foods. They contribute many essential nutrients to the human diet. In addition to being a high biological value source of protein, many essential health-promoting micronutrients are most efficiently or exclusively supplied to the human body through the intake of foods of animal origin (Stanton, 2022). Meat is a nutritious food source, highly valued by consumers worldwide. However, its composition makes it highly perishable and it must preserve. One of the oldest methods of preservation is salting and curing. Curing is the process of adding salt to the meat to inhibit the growth of spoilage microbes and to develop the texture and flavour of the product. The oldest known way of introducing salt is to cover the meat with salt crystals. The salt dissolves in the moisture on the surface of the meat to form a saturated salt solution. The difference in concentration between the surface saturated salt solution and the inner layers of the meat causes the salt to migrate into the meat (Toldrá, 2004). Salt migration is a slow process that depends on many factors. Various techniques have been developed to speed it up. For example, soaking meat in a brine solution can shorten the curing time by making the salt available in a dissolved form to migrate into the meat. A "newer" way to speed up curing is to inject brine or pickling liquid into the meat, which can reduce curing time by shortening the salt migration path. It is usually combined with tumbling, in which the injected meat is mechanically loosened in a rotating drum, thus helping to distribute the brine more quickly in the meat. In recent decades, the development of meat curing technology has focused on improving the energy efficiency of injection and tumble equipment. No real development has taken place, or has been kept within the walls of laboratories. It is therefore justified to investigate different alternative techniques. Examples include high hydrostatic pressure treatment, pulsed electric field (PEF) (Cropotova et al., 2021), curing under vacuum (Tomac et al., 2020), freeze-thawing (Ortiz et al., 2021), and ultrasound. These include some promising and some less promising. Based on literature results, ultrasound can be classified in the former category (Sergeev et al., 2009; Xiong et al., 2020). The accelerating effect of ultrasound on pickling is mainly due to cavitation, an additional phenomenon accompanying ultrasound. Cavitation is the creation of microscopic cavities in a fluid by ultrasound. These cavities either collapse or oscillate for longer or shorter periods. When collapsed, they generate high velocity (around 400 km/h) fluid flows (microjet) that can cause physical damage to solid surfaces, capable of penetrating cell walls (Cárcel et al., 2012). This type of damage to cell walls increases their permeability and membrane permeability, which allows for a faster penetration of different substances (e,g. salt during curing) into the cell (Cárcel et al., 2007). Several studies have demonstrated a faster penetration of salt into meat during curing using ultrasound (Carlos et al., 2007; Ozuna et al., 2013; Siró et al., 2009). It makes ultrasound a promising alternative technique. Ultrasound alone is known to have a high probability of accelerating the curingprocess. However, there is currently no information available on whether curing can be further accelerated by not only exploiting the effect of the cavitation cavities created by ultrasound, but also by directly creating additional cavitation cavities, or bubbles, in the curing bath by hydrodynamic means. This topic offers itself as a new field of research in meat curing technology and aims at basic research that can be applied in practice within a short time frame.

As there is currently no information available on the effect of intensifying cavitation by generating microbubbles in the brine on salt intake, the objective of my research is to investigate the effect of ultrasound and microbubbles on salt and water diffusion, mass transport processes, protein status, microstructure and quality properties of pork chops. To this end, the following experiments are carried out:

- Dry and wet curing of pork loin meat rolls (d=15 mm, h=80 mm) and combined wet curing with ultrasound (20 kHz; 100 W) in a 26.3 m/m% salt brine for 180 min. It is to test the effect of ultrasound.

- Wet curing of pork loin meat rolls (d=15 mm, h=80 mm), ultrasound assisted brining (20 kHz; 100 W) and ultrasound assisted brining with microbubbles (20 kHz; 400 W) in a 20 m/m% brine for 180 min. It is to test the combined effect of ultrasound and microbubbles.
- Small-scale pilot wet curing of boneless pork loin in a 20 m/m% brine and ultrasound assisted brining with microbubbles (35 kHz, 1 kW; 2 lap irradiators). My aim is to investigate the combined effect of ultrasound and microbubbles on a whole piece of meat in a small-scale facility.

2. MATERIALS AND METHOD

1.1. Description of the curing experiments

In my work, I used skinless and boneless pork loin (*m. Longissimus dorsi*, pH 5.82 ± 0.05) in my laboratory experiments. I cut meat cylinders with a diameter of d = 15 mm and a height of h = 30 mm parallel to the fibre line.

In the small-scale, pilot experiment, I used boneless, skinless pork chops (*m. Longissimus dorsi*, pH 5.58 ± 0.06).

The first experiments in this work were dry salting, wet curing and ultrasound assisted brining, followed by a new experiment with wet curing, ultrasound assisted brining and ultrasound assisted brining with microbubbles. During the dry curing process, I covered the meat rolls with a curing salt solution by laying the meat rolls on a bed of salt and then covering the surface of the meat rolls with curing salt solution at a 1:10 meat to salt ratio. As the curing salt applied to the meat surface dissolves in the surface moisture content of the meat to form a saturated brine solution (26.3 m/m%), I prepared a saturated brine solution using curing salt for the wet curing and the ultrasound assisted brining. The wet curing and the ultrasound assisted brining were carried out in a stainless steel vessel with a meat to brine ratio of 1:25. The ultrasound assisted brining was performed with an Active Ultrasound Laboratory ultrasonic handler (Ultrasonotech Team, Mosonmagyaróvár, Hungary) with a frequency of 20 kHz and a power of 100 W, at an intensity of 5.09 W/cm^2. Experiment II was carried out in a 20 m/m% brine, in accordance with the brine salt concentration used in the industry. Wet curing and ultrasound assisted brining were performed as described above. In the ultrasound assisted brining with microbubbles, microbubbles were created in the curing bath by a gas-liquid mixing pump (Type: YL8022, Model: 25GO-2SS, 1.1 kW, Guangzhou Ozone Environmental Technology Co. GZ, China), which, according to the manufacturer's information, produces bubbles with a size range of 20-30 µm. The microbubbles were formed by mixing atmospheric air into a bath at a flow rate of 100 L/min under continuous operation. During the brining process, the meat cylinders were immersed in the brine by placing them in a test tube rack and placing the rack on an ultrasonic emitter (20 kHz, 400 W, 14.14 W/cm2, Ultrasonotech Team, Mosonmagyaróvár, Hungary) placed at the bottom of the pickling vessel. The brining was performed at a meat to brine ratio of 1:500 and at 8 °C, provided by a cooling system built into the system.

To perform the small-scale pilot ultrasound assisted brining with microbubbles I used 2 ultrasonic lap lamps with a frequency of 35 kHz each and a power of 1 kW. The raw materials were placed above the ultrasound emitters at a height of 3 meat layers (8 per layer). In order to maximise the surface area of the raw material in contact with the ultrasound waves and the pickling solution, plastic spacer grids 100 mm high were placed between the rows of raw material. To brining I used brine with a salt concentration of 20 m/m%. The ultrasound assisted brining with microbubbles was carried out using the following program steps:

Step 1: 10 minutes of microbubble formation in the brine (without ultrasound irradiation)

Step 2: 30 minutes of ultrasound irradiation (without microbubble formation)

Step 3: 20 minutes rest (without ultrasound irradiation and microbubble formation).

I repeated the steps in 16 cycles per day, with the goal of achieving 8 hours/day of net ultrasound irradiation. The cycles were repeated for 8 days, adjusted to the factory curing time of the leather pork loin. The curing was performed in a curing room at 8 °C with a meat to brine weight ratio of 1:12. After curing, the raw materials were subjected to cold smoking (<20 °C) for 48 hours followed by maturation (75% RPT, 8 °C) for 30 days. In the small-scale pilot-scale experiment, the product prepared by wet curing without microbubbles and ultrasound irradiation was used as a control sample.

1.2. Calculations and measurements

To calculate the salt diffusion, the salt content (C) of the meat samples was determined by the Mohr's argen-tometric method (AOAC, 1990). To determine the moisture content for the water diffusion calculation, the samples were dried at 105°C to constant weight. For the calculation of salt and water diffusion, the equilibrium salt (Ceq) and moisture (Xeq) contents of the meat samples were determined by measurement in laboratory experiments I and II. In Experiment III, the equilibrium salt and moisture content of boneless pork chops with skin was determined by calculation according to Körmendy (1991). To describe salt and moisture diffusion and mass transport, I used the model equations [1] - [5]. The calculations were based on the assumption that unidirectional (radial) diffusion occurs in the meat samples used in the experiment due to their geometric dimensions, and that the salt concentration in the marinade juice is constant during the marination.

Marabi et al., 2003	$\frac{C_t - C_0}{C_\infty - C_0} = 1 - e^{-\left(\frac{tD_s}{l^2}\right)^\beta}$	[1]
Abbasi et al., 2012	$\frac{C_t - C_0}{C_\infty - C_0} = 1 - \sum_{n=1}^{\infty} \frac{4}{\mu_n^2} \exp\left(-\mu_n^2 \frac{D_s t}{R^2}\right)$	[2]
Telis et al., 2003	$\frac{C_t - C_0}{C_\infty - C_0} = 1 - \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} exp\left(\frac{-D(2n+1)^2 \pi^2 t}{R^2}\right)$	[3]
Peleg, 1988	$SC = SC_0 + \frac{t}{k_{s1} + k_{s2} t}$	[4]
Zugarramurdi and Lupín, 1980	$SC = SC_0 exp(-k_s t) + SC^\infty (1 - exp(-k_s t))$	[5]

Changing salt (C) for moisture (X) in the equations [1]-[5], water diffusion coefficient (Dv) can be calculated. The diffusion coefficient (D) was optimized using MS Excel 365 SOLVER using a non-linear method to minimize the Root Mean Squares of Error (RMSE) between measured and calculated salt and water content values. The "goodness of fit", was calculated by the coefficient of determination (R^2). To determine the water binding capacity of the samples, I measured the prebrined weight (mt,0) and then the post-brined weight (mt) of the meat samples. The difference between these was used to characterize the water binding capacity expressed as a % of the pre-marinated weight. The water retention capacity indicates how much water the meat is able to absorb or release during the different curing operations, based on its initial weight. Protein denaturation was measured by differential scanning calorimetry (DSC) in a SETARAM MicroDSC III (SETARAM Instrumentation Caluire, France). Measurements were performed on 217.7±10 mg samples taken from the central part of the meat cylinders in the longitudinal direction of the cylinders at a temperature range of 25-90 °C and a heating rate of 1 °C/min. Microstructures of meat samples were performed on dehydrated sections using a Thermo Scientific™ Prisma™ E SEM (Waltham, Massa-chusetts, USA) scanning electron microscope.

Texture measurements were taken using an SMS TA.XT Plus (Stable Micro Systems Ltd., UK) equipped with a 500 N load cell. The Texture Profile Analysis (TPA) measurement method was used to characterize the texture of the meat cylinders. Stock measurement of leathery loin samples was performed using a Warner-Bratzler (WB) load cell. Water activity was measured using LabMaster aw (Novasina AG, Switzerland). Color measurement was performed with a Minolta CR 400 (Konica Minolta Inc., Japan) tristimulus colorimeter. The data were evaluated in CIELab colorimetric scale, where L* represents lightness, a* represents redness and b* represents yellowness. The difference in color intensity (ΔE*) between wet cured and microbubbles and ultrasound assisted brined samples were calculated from the mean L*, a* and b* values measured on the respective measurement days. The pH was measured using a Testo 206-pH2 (Testo GmBh, Austria) pH meter with temperature compensation. Statistical analysis of variance (ANOVA) was performed on the measured data using IBM SPSS Statistics 23.0 (IBM Corp., USA) with 95% confidence interval ($p<0.05$). An exponential equation [6] was fitted to the results of water binding capacity, stock, water activity and colour measurements:

$$y = A \times (1 - exp(-k \times t^{n})) \qquad [6]$$

3. RESULTS

The ultrasound wet curing in saturated brine achieved significantly higher salt concentrati-ons than dry curing. There is also a significant difference between the salt content values of wet and ultrasound assisted wet cured samples. The moisture content of the samples was the lowest during the ultrasound assisted wet curing. There was no significant difference between the samples. To compare the diffusion rates, salt (Ds) and water (Dv) diffusion factors were deter-mined using different mathematical models (Abbasi model, Marabi model, Telis model). In examining the accuracy of the models, I found that the Abbasi model showed the closest fit between measured and calculated values for both salt and water content measurement results. Wet curing supplemented with ultrasound achieves 2 times faster salt diffusion than dry curing and 1.5 times faster than wet curing. When testing the diffusion coefficient of water, I obtained a value 1.6 times higher with ultrasonic curing than with dry curing and 1.3 times higher than with wet curing. Empirical models (Peleg model, Zugarramurdi and Lupín models) were used to characterise the kinetics of mass transfer. Indicators calculated using these models also sup-ported the faster salt uptake and moisture reduction achieved with ultrasonic treatment. Based on the equilibrium salinity (Steq) values calculated using the Peleg model, ultrasonic wet cu-ring can significantly reduce curing time compared to dry and wet curing. The water holding capacity is reduced for all curing modes, indicating dehydration of the samples. This is related to the denaturation of the meat proteins, which already partially occurred after 15 minutes of curing, with the myosin denaturation peak disappearing at this sampling point for all curing modes. The denaturation enthalpy values of meat samples showed a decreasing trend, with the amount of denaturable proteins decreasing the most in the ultrasound assisted wet curing. The effect of the decrease in water binding capacity is also evident from the electron microscopy images and the results obtained from the stock measurements. As a result of the curing, the diameter of the fibres decreased and the hardness of the samples increased. Ultrasound can achieve a softer texture than the other two curing methods.

The introduction of microbubbles in the brine further enhances the salt diffusion. The ult-rasound assisted wet curing with microbubbles achieves a significantly higher salt content after 120 minutes of treatment than the ultrasound assisted brining. In Experiment II, the Abbasi mo-del also showed the best relationship for salt diffusion, while the Telis model showed the best relationship for water diffusion. Ultrasound treatment in a 20 m/m% salt brine achieved 1.3 times faster salt diffusion than conventional wet curing, while ultrasound treatment with microbubble was 1.6 times faster. The ultrasound assisted briningwith microbubbles can achieve 1,7 times faster water diffusion than traditional wet curing and 1,2 times faster than ultrasound assisted brining. Based on the Peleg model, microbubble assisted ultrasound brining can reduce curing time by 30% compared to conventional wet curing and 11% compared to ultrasound assisted brining. Water binding capacity also showed a decreasing tendency throughout the ex-periment, similar to that observed in Experiment I. The dehydration of the samples is caused by the phenomenon of "salting out", which is already observed at the first sampling point (15th minute). At this point (≥ 3.25% salt content), denaturation of proteins was already observed, with no denaturation peaks representing myosin and sarcoplasmic proteins. When 20% brine was applied, despite the loss of water, swelling of the fibres was detected after 180 minutes of brining. In the images of the microbubble combined ultrasound sample, tiny pores of about 2-3 µm in diameter are observed on the surface of the meat fibres, presumably due to damage ca-used by the collapse of the microbubbles. This structure-destroying effect results in an even softer texture than ultrasound alone.

The use of microbubbles in laboratory-scale brining showed promising results, so I per-formed the experiment in pilot scale. For the industrial experiment, I used leather chops. Based on the salinity results, I concluded that ultrasound assisted wet curing supplemented with mic-robubbles can significantly shorten brining and ageing time due to the uniform and faster distribution of the brine throughout the meat. In Experiment III, the Marabi model was the most appropriate for the salt and water diffusion studies. Based on the salt diffusion coefficients cal-culated using the model, a 1,25 times faster salt diffusion can be achieved by using microbubb-les compared to traditional wet curing. Water diffusion values 1,3 times higher were obtained for ultrasound assisted treatment combined with microbubble grafting. According to the Codex Alimentarius Hungaricus 1-3/13-1, water activity (aw) of cured products must not exceed 0.91. Based on the water activity values, the addition of microbubbles to the brine results in a 14-day shorter brining and ageing time. In the case of the leathery loin, the lightness (L*) value of the ultrasound combined with microbubbles samples was significantly lower. There was no sta-tistically supported effect of brining methods on redness (a*) and yellowness (b*). However, at the end of the experiment, the ultrasound combined with microbubble grafting showed sig-nificantly softer samples. The pH values increased during the experiment. The pH values were not significantly affected by the brining methods.

The results show that the ultrasound combined with microbubble brining during meat cu-ring is highly effective in accelerating salt and water diffusion, reducing water activity and achieving softer stock. It can shorten curing and ageing times and improve product quality.

In the course of my PhD work, I have made several new findings, in addition to new chal-lenges in academia that could form the basis for further research.

4. CONCLUSIONS AND RECOMMENDATIONS

In my PhD thesis, I conducted three experiments to investigate the effects of different curing methods, ultrasound and ultrasound with microbubbles during meat brining.

My results show that at the end of the 180-minute curing period, ultrasound assisted brining achieves higher salt content compared to both dry and wet curing. I hypothesise that a possible reason for this is that the ultrasound-induced cavitation generates a so-called "sponge effect" in the meat, which leads to the formation of microchannels in the cell walls. These microchannels allow faster diffusion processes during the pickling process. Based on the calculated diffusion coefficient values, I found that ultrasonic wet pickling achieves faster salt diffusion compared to wet and dry curing. I observed a decreasing trend in the moisture content of the meat samples. By using a saturated brine, the concentration difference between the meat and the brine is so big that the osmotic "pull" of the brine is greater than the diffusion of salt ions (Na^+, Cl^-) surrounded by water molecules towards the meat. The moisture content of the meat samples decreased most during the experiment when ultrasound assisted brining was used. This treatment showed much faster water diffusion compared to wet and dry curing. Using Peleg's model, I found that the initial rate of salt uptake and water loss is achieved with ultrasound assisted wet curing. The high salt concentration achieved in the meat causes denaturation of proteins, resulting in dehydration of the samples. Scanning electron microscopy images showed that the application of curing and ultrasound led to a certain degree of deformation of the myofibrils, with a reduction in the thickness of the fibres and their different sizes. Due to the ultrasound-induced cavitation phenomenon, the surface of the meat became uneven and its structure was destroyed, resulting in a softer texture compared to dry and wet cured samples.

In my tests, I observed that the additional microbubble introduced into the brine further increases the diffusion processes, resulting in a higher salt concentration in the meat. I also observed dehydration of the samples when using a 20 m/m%

brine concentration, with pork loin meat samples showing a reduction in moisture content of between 11-15% during the experiment. The rate constants suggest that the use of microbubbles has a greater effect on the initial rate of moisture removal than on salt uptake. The water binding capacity of the samples in this experiment also showed negative values, decreasing continuously with the brining time. This is the result of the depolymerisation of meat proteins on salt, called salting-outThe denaturation of meat proteins also occurs more rapidly as a result of the salting. The amount of denaturable proteins is reduced to a greater extent by the use of ultrasound assisted brining combined with microbubbles, resulting in a higher denaturation of meat proteins, which is a more digestible protein source. Microscopic images showed a swelling of the fibres, even though the samples were dehydrated. It can be concluded that the swelling is not due to water retention, but presumably to ultrasound-induced structural changes, which are still present when 20 m/m% brine is applied. The introduction of microbubbles results in the formation of tiny pores on the surface of the meat, and the structure is therefore more fragmented, so that the texture is more tender than when ultrasound alone is applied.

The results obtained from salt content measurement in Experiment III also show the effect of ultrasound combined with microbubbles in brine on salt retention. Microjets formed by the collapse of microbubbles facilitate the diffusion of salt into the meat. The application of the combined treatment also had a positive effect on the kinetics of salt diffusion and on the equilibration of the salt content in the product. In traditionally cured products, one of the main objectives is to remove moisture from the product. Removal of moisture also reduces the water activity (aw) value, which indicates the shelf life of the product. For cured products, the water activity value should be up to 0,91. The use of ultrasound combined with microbubbles in brine treatment can shorten the curing and ageing time by about 14 days compared to wet curing under the experimental conditions. The colour of the skinned loin samples changed during the curing and ageing process, and by the end of the experiment the samples were significantly darker and significantly redder than the raw meat. The curing methods had a significant effect on the value of the lightness factor (L*), with samples ultrasound combined with microbubbles in brine being significantly darker, which can be explained by faster salt penetration and faster water release. Due to the drying of the products, the hardness of the samples increased steadily throughout the experiment, with a more significant increase in the ageing phase. I have also experienced the destructive effect of ultrasound under industrial conditions, and at the end of the experiment, intensifying the cavitation resulted in significantly softer texture. I observed that the pH of the meat samples increased during the curing and ageing experiment, with a more significant increase at the beginning of ageing, which may be related to the presence of free amino acids resulting from the onset of proteolysis.

Based on the results of my measurements, I found that the application of ultrasound can accelerate the diffusion processes during the curing process. However, the phenomenon of salting-out must be taken into account, which, according to my results, occurred at 3.25-3.58 m/m% salt content.

Intensifying the cavitation phenomenon by introducing microbubbles into the brine can be a useful addition to ultrasound assisted brining technology to achieve faster salt and water diffusion, faster protein denaturation, faster water activity reduction and softer texture. The use of this treatment would allow both precision curing technology and faster response to consumer demand.

NEW SCIENTIFIC RESULTS

1. I have found that wet curing of pork loin meat cylinders (d=15 mm, h=80 mm) combined with ultrasound at 20 kHz, 5.09 W/cm^2 intensity, results in two times faster salt diffusion and 1,6 times faster water diffusion compared to dry curing in saturated brine for 180 min.

2. I have found that ultrasound assisted brining of pork loin meat cylinders (d=15 mm, h=80 mm) combined with microbubbles at 20 kHz, 5.09 W/cm2 intensity, results in 1,2 times faster salt and water diffusion compared to ultrasound assisted brining with 20 m/m% salt concentration for 180 min.

3. I have found that ultrasound assisted brining of pork loin meat cylinders (d=15 mm, h=80 mm) in saturated brine at 8°C at 20 kHz at 5.09 W/cm2 can reduce the brining time by 43% compared to dry curing and 29% compared to wet curing, when ultrasound assisted brining combined with microbubbles with 20 kHz at 5.09 W/cm2 in 20 m/m% brine can reduce the curing time by 30% compared to wet curing and by 11% compared to ultrasound assisted brining at a maximum salt content of 5 m/m% of raw ham, based on the Peleg model.

4. I have found that no denaturable protein was detectable when pork loin meat cylinders (d=15 mm, h=80 mm) were brined at 8 °C in a 20 m/m% brine combined with 20 kHz ultrasound at 5.09 W/cm2 for 60 min (6.96 wt% and 7.51 wt% salt) in a 20 m/m% brine at 8 °C and in a 20 kHz ultrasound at 5.09 W/cm2 for 60 min combined with microbubbles.

5. I have found that 20 kHz, 5.09 W/cm2 ultrasound assisted brining for 180 min combined with microbubbles in 20 m/m% brine causes structural changes in pork loin fibres, increasing swelling by 28% and creating microscopic pores on the surface.

6. I have found that using 35 kHz, 2.74 W/cm2 ultrasound assisted brining combined with microbubbles can shorten the curing and ageing time by 36% based on water activity compared to wet curing when 2.3-2.5 kg of boneless pork loin cured in a 20 m/m% brine.
7. I have found that 35 kHz, 2.74 W/cm2 ultrasound assisted brining combined with microbubbles for 8 days and 30 days ageing of 2.3-2.5 kg of boneless skinless pork loin resulted in a product 11% softer than that obtained with wet curing alone.

LIST OF JOURNAL PUBLICATIONS IN THE FIELD OF STUDIES

Visy, A.; Jónás, G.; Szakos, D.; Horváth-Mezőfi, Zs.; Hidas, K. I.; Barkó, A.; Friedrich, L. (2021): Evaluation of ultrasound and microbubbles effect on pork meat during brining process. ULTRASONICS SONOCHEMISTRY 75 Paper: 105589, 8 p. **D1**

Visy, A.; Hidas, K. I., Barkó, A., Nguyen, L. L. P., Friedrich, L., Jónás, G. (2021): Effect of wet-curing on physical properties and proteins of cured ham. PROGRESS IN AGRICULTURAL ENGINEERING SCIENCES 17: S1 pp. 145-155., 11 p. **Q3**

Visy, A., Hidas, K. I., Surányi, J., Jónás, G., Friedrich, L. (2020): Monitoring of salt content during the dry salting of ham. PROGRESS IN AGRICULTURAL ENGINEERING SCIENCES 16 S2 pp. 45-54., 10 p. **Q3**

Visy, A., Csonka, J., Hidas, K. I., Jónás, G., Friedrich, L. (2020): Examination of the parameters of active ultrasound treatment for the quality of curing. JOURNAL OF HYGIENIC ENGINEERING AND DESIGN 30 pp. 120-124. 5 p. **Q4**

Visy, A., Hidas, K. I., Csonka, J., Friedrich, L., Jónás, G. (2019): Combined effect of various nitrite concentration and high pressure treatment on functional characteristics of raw meat batter. JOURNAL OF HYGIENIC ENGINEERING AND DESIGN 26 pp. 47-51., 5 p. **Q4**

Visy, Anna; Hidas, Karina Ilona; Koósz, Zsuzsanna; Barkó, Annamária; Horváth-Mezőfi, Zsuzsanna; Lien, Phuong Le Nguyen; Friedrich, László; Jónás, Gábor (2021): Az ultrahang és a nagy hidrosztatikus nyomású kezelés kombinált hatásának vizsgálata a hús pácolása során. ACTA AGRONOMICA ÓVÁRIENSIS 62. III pp. 88-110., 23 p.

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