Fitting and evaluating diffusion models for dry salting, wet curing and ultrasonic curing

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Introduction

Curing is a widely used preservation and character building process in the meat industry, which is a major limitation on the capacity of meat plants due to its significant technological time. We compared three curing processes: dry salting (traditional process), wet curing (a process common in the industry) and wet curing with high-intensity active ultrasound treatment (an innovative process). Taking into account that the diffusion of salt has the greatest impact on the technological time of curing, and the diffusion of moisture on the yield of the product, we determined these two diffusion constants for all three curing processes. Knowing these, the relative effect of each treatment on diffusion compared to dry salting could be determined. Based on the accuracy of the fit of the different diffusion models applied to the measurement results, we evaluated the applicability of these models in the case of curing meat.

Materials and Methods

The raw material of the tested sample was pork loin. A total of 69 cylinders with a length of 80 mm and a diameter of Ø15 mm were cut from the meat and their initial weight was measured. The pH was between 5.49 and 5.97, so PSE and DFD meat defects were excluded. See Table 1 for the layout of the experimental samples.

Table 1. Number of independent samples in the experiment

DS: dry salting, WP: wet curing, US: wet curing + ultrasound

Treatment	Time							
	0 min	15 min	30 min	60 min	90 min	120 min	150 min	180 min	~2 days
control - raw	3								
control - equalized									3
DS		3	3	3	3	3	3	3	
WP		3	3	3	3	3	3	3	
US		3	3	3	3	3	3	3	

Control samples were set up without treatment and held in saturated saline until equilibration (approximately 2 days). **Dry salted samples** were placed under complete salt coverage. The samples to be wet cured were immersed in a saturated marinade solution. **For the wet cured samples wit US**, the added ultrasonic treatment was applied (400 W, 19 kHz), with Ø60 mm radiating head, with an acoustic energy of 14.1474 W/cm^2. The salt solution was saturated in case of both wet curing method.

The dry matter content of the samples was determined by drying at 105°C. Knowing the dry matter, the water content [m/m%] was determined. Salt was determined by Mohr method. To determine the diffusion coefficient of salt and water, three literature diffusion models (Martuscelli *et al.* (2017), Abbasi *et al.* (2012) and Telis *et al.* (2004)) were fitted to the measurement results. The diffusion coefficient was determined by regression while minimizing the RMSE. The effect of the method and the duration on salt and water content was analyzed by ANOVA.

Results and Discussion

Based on ANOVA, it can be determined that both treatment and duration have a significant effect on salinity (see Figure 1). Treatment and duration also have a significant effect on water content, but according to the Tukey test, the use of ultrasound within wet pickling cannot be clearly distinguished (see Figure 2). The difference in water content between dry salting and wet processes was examined using regression analysis: during the application of **both wet curing methods, the excess moisture content** of the 80 mm x Ø15 mm size meat sample **approaches +4.58 m/m%** along the saturation curve (see Figure 3). According to the model of Abbasi *et al.* (2012), the diffusion coefficient of salt is 4.22 * 10^{-10} m^2/s, which can be improved by 36,3 % using wet curing and by 102,6 % using wet curing assisted by active ultrasound. The other two models also found a similar relative effect compared to dry salting (see Figure 4). According to the model of Telis *et al.* (2004), the diffusion coefficient is 2.42 * 10^{-9} m^2/s. According to all three mathematical models, the diffusion constant of water decreases by an order of magnitude (75-80 %) in the case of wet processes. Due to this, the use of wet curing results in a more favorable yield than traditional dry curing. It is interesting to observe that the addition of ultrasound to wet curing does not improve the favorable effect on the yield, since in this case the diffusion coefficient only shows a decrease of about 65 % (see Figure 5).

Conclusions

Our results confirm the previous scientific findings, according to which **active ultrasound** can gain importance in the meat industry **not primarily by itself**, but when used at low intensity **as part of a combined process**.

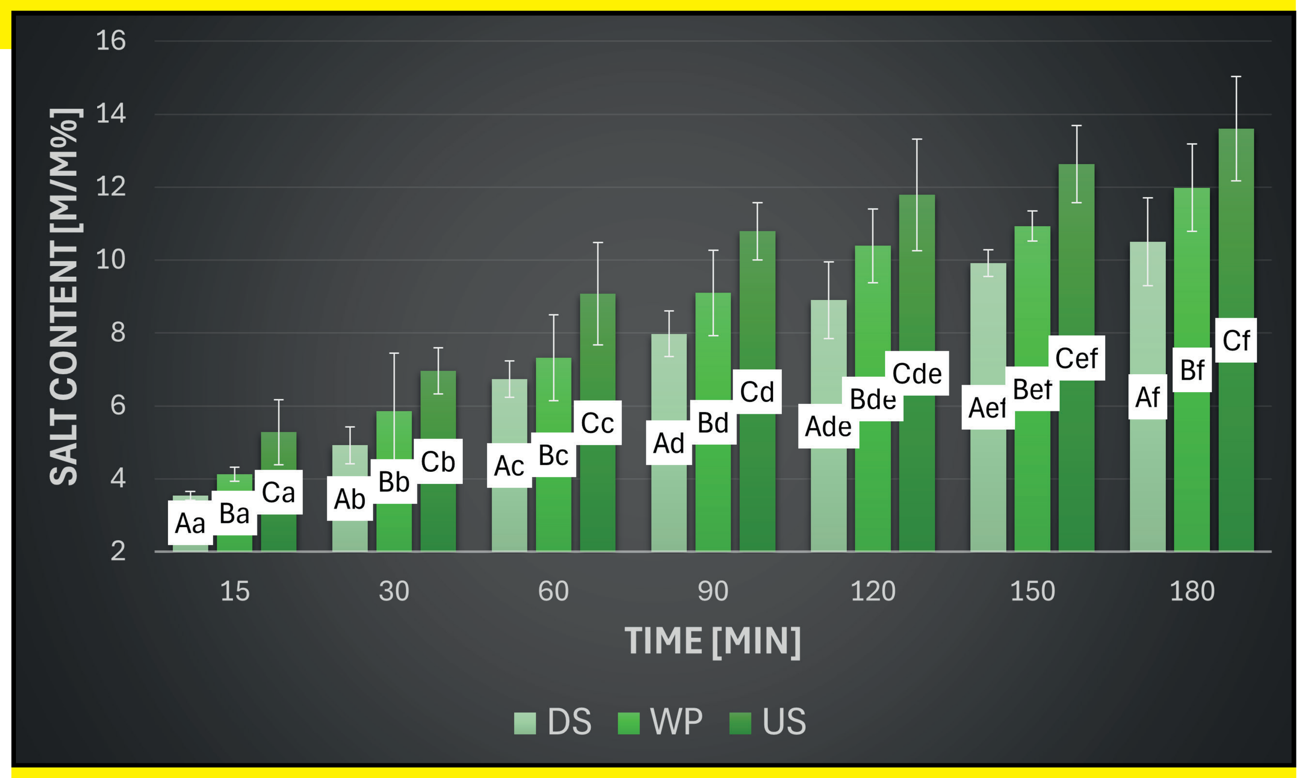

Figure 1. Salt content and its standard deviation + Tukey

Treatments: DS: dry salting, WP: wet curing, US: wet curing + ultrasound

A, B, C: separable processes | a, b, c, d, e, f: separable treatment times

Significance: for Treatment $F(2;42)=34.252; p<0.001$, for Time: $F(6;42)=72.368; p<0.001$

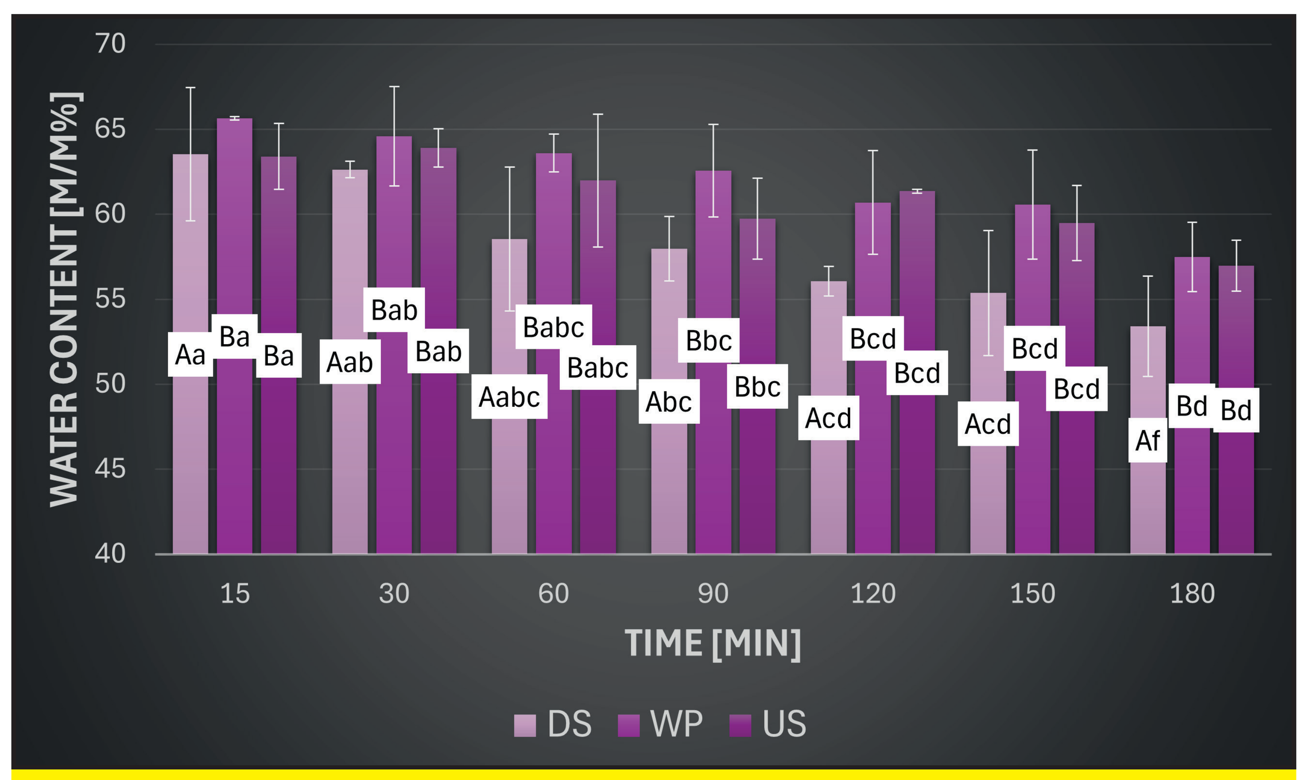

Figure 2. Water content and its standard deviation + Tukey

Treatments: DS: dry salting, WP: wet curing, US: wet curing + ultrasound

A, B: separable processes | a, b, c, d, e, f: separable treatment times

Significance: for Treatment $F(2;42)=13.451; p<0.001$, for Time $F(6;42)=11.957; p<0.001$

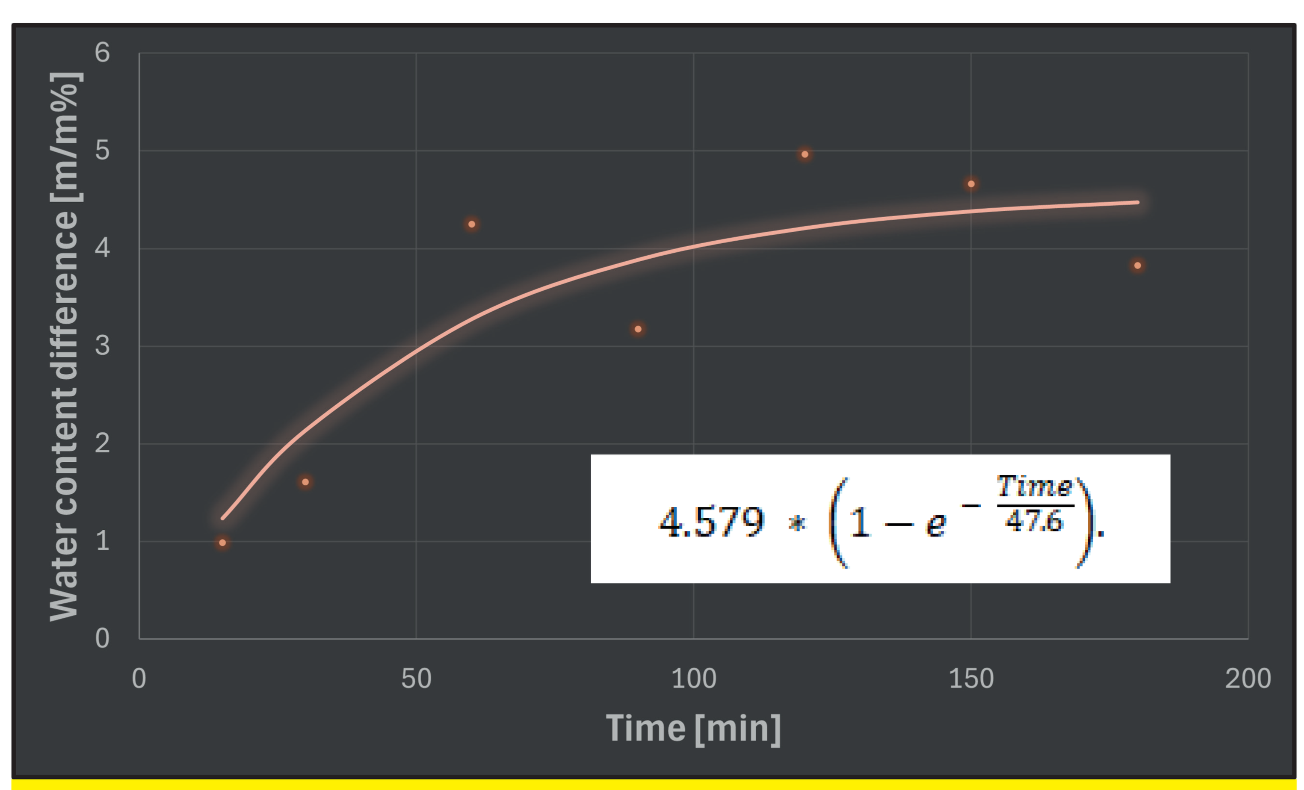

Figure 3. Average water content differences between dry salting and wet curing methods with regression ($R^2=0.796$)

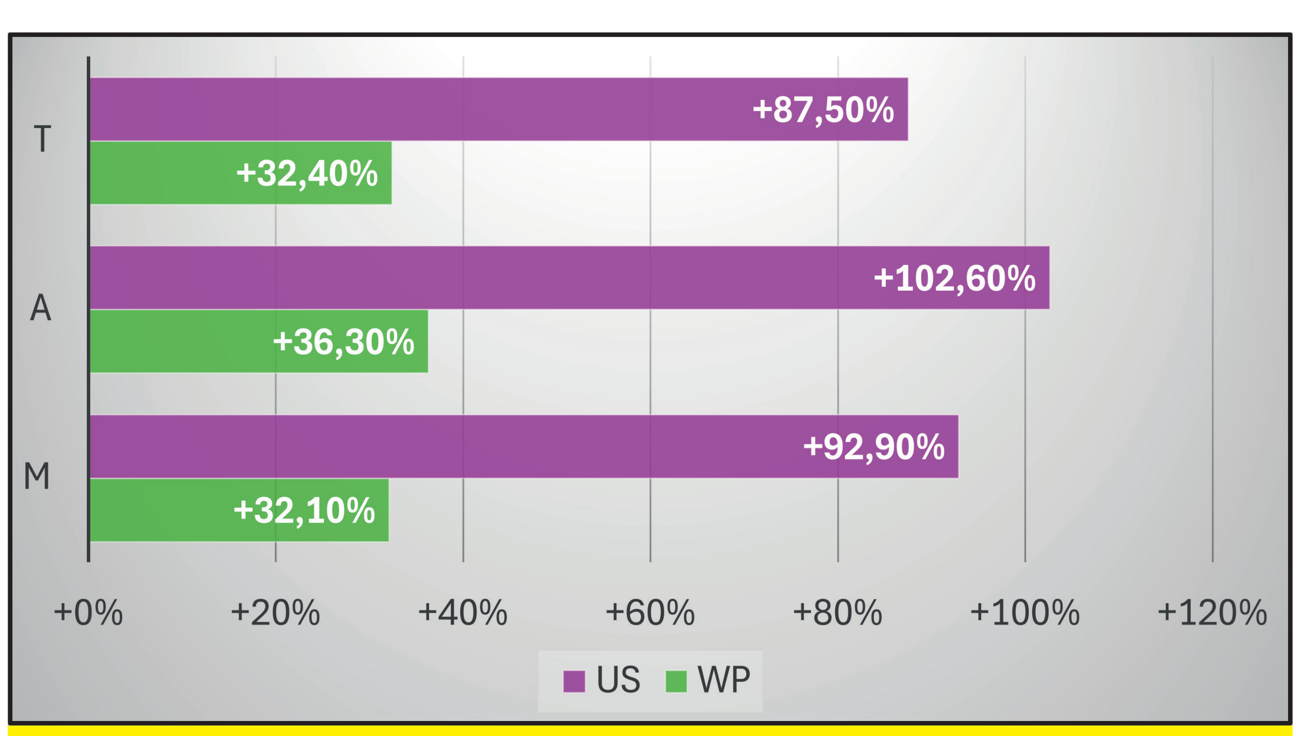

Figure 4. Effect of wet and ultrasonic wet curing on improving **salt diffusion coefficient** compared to dry salting

Treatments: **WP: wet curing**, **US: wet curing + ultrasound**

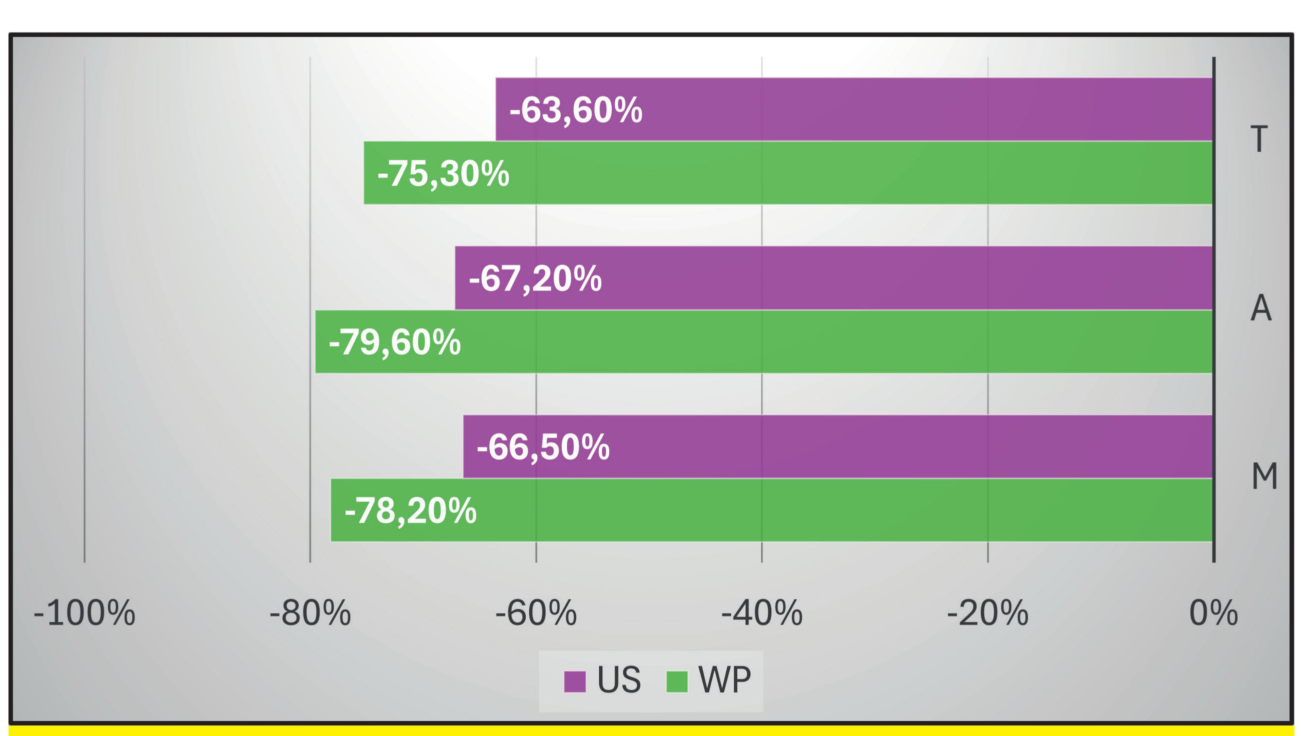

Figure 5. Effect of wet and ultrasonic wet curing on modifying **water diffusion coefficient** comp. to dry salting

Treatments: **WP: wet curing**, **US: wet curing + ultrasound**

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