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EFFECTS OF ULTRASOUND-ASSISTED TUMBLING ON SODIUM CHLORIDE TRANSFER OF BEEF

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I. INTRODUCTION

Brining is one of the critical techniques during meat processing, which can determine the quality of meat products. However, the complex structure of meat limits the rate of brine diffusion, resulting in a long curing period and high processing costs [1]. Applying ultrasound-assisted tumbling technology to improve meat quality is gradually arousing the interest of researchers. To better understand the effects of ultrasound-assisted tumbling on the diffusion characteristics and the contents of NaCl in beef [2], this study analyzed the NaCl diffusion kinetics using five mathematical models.

II. MATERIALS AND METHODS

2.1 Brine preparation and tumbling processing

The brine (w/v) used in the experiments was prepared from distilled water, 8.6% NaCl, and complex phosphates mixture (0.34% sodium hexametaphosphate, 0.34% sodium tripolyphosphate, and 0.17% sodium pyrophosphate). The beef samples were randomly allocated into five groups: one single tumbling group (ST) and four ultrasound-assisted tumbling groups (UT). Subsequently, the samples and brine were poured into the tumbling drum at a ratio of 100:35 (w/v). The experiment included six tumbling times (30, 60, 90, 120, 150, and 180 min) and four ultrasonic power levels (100, 300, 500, and 700 W) [3].

2.2 Determination of salt content and analysis of salt kinetic

After tumbling processing, the samples were removed from the tumbler drum and washed with deionized water. To eliminate edge effects, the salt content was measured at a distance of 1 cm from the meat surface. The 5 g meat samples were cut using a scalpel and homogenized with deionized water to dissolve the aqueous extracts. The supernatant was measured by a digital salt meter and the salt content was expressed as g/100 g meat [4]. The salt kinetic in beef was determined according to the five mathematical models (Diffusion; Weibull; Peleg; Azuara; Zugarramurdi and Lupin) using the following Eqs. (1), (2), (3), (4), and (5).

$$\frac{C_{s,0}-C_{s,t}}{C_{s,0}-C_{s,\infty}}=1-\sum_{n=0}^{\infty}\frac{8}{(2n+1)^2\pi^2}e^{\frac{-D_S(2n+1)^2\pi^2 t}{L^2}} \quad (1)$$

$$\frac{C_{s,g}-C_{s,\infty}}{C_{s,0}-C_{s,\infty}}=exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \quad (2)$$

$$C_{s,g}=\frac{t}{k_{s,1}+k_{s,2}t} \quad (3)$$

$$C_{s,g}=\frac{k_{s,3}tC_{s,\infty}}{1+k_{s,3}t} \quad (4)$$

$$C_{s,g}=C^{s,\infty}\left[1-exp(-k_{s,4}t)\right]+C_{s,0}exp(-k_{s,4}t) \quad (5)$$

where $C_{s,0}$ represents the initial salt content (g/100 g), $C_{s,t}$ is the salt content at time t (s), $C_{s,g}$ is the increase in salt content at time t, $C_{s,\infty}$ corresponds to salt content at brining equilibrium, D_s indicates the salt diffusion coefficient (m^2/s), L is the thickness of the beef sample (m), α is the scale parameter (h) and β is the shape parameter, $k_{s,1}$, $k_{s,2}$, $k_{s,3}$, and $k_{s,4}$, are the model parameters.

2.3 Statistical analysis

The results are shown as the mean ± standard error. All data were analyzed by SPSS 20.0 software (Chicago, IL, USA), and significant differences ($p < 0.05$) were determined by Duncan's multiple-range test in one-way analysis of variance and Student's t-test. Mathematical models were fitted to experimental data through nonlinear regressions using OriginPro 8.0 (OriginLab Corporation, Northampton, MA, USA). To assess the adequacy of the model to the experimental data, the coefficient of regression (R^2) and the root mean square error ($RMSE$) were used. The RMSE was the difference between the predicted and experimental values of salt content.

III. RESULTS AND DISCUSSION

As shown in Table 1, the D_s, $k_{s,3}$, and $k_{s,4}$ values of UT groups (300, 500, and 700 W) were significantly higher than those of ST group ($P < 0.05$), indicating that UT treatment could accelerate the diffusion of NaCl into meat compared with ST treatment. The superiority of ultrasound-assisted tumbling treatment might be attributed to ultrasonic cavitation, which generates microjets that disrupt the myofibrillar structure of beef [3]. In addition, all tested models (Diffusion; Weibull; Peleg; Azuara; Zugarramurdi and Lupín) accurately predicted the experimental salt content data ($R^2 \geq 0.975$) [4]. However, the Weibull model exhibited a higher R^2 and a lower *RMSE* compared to the other models, indicating a smaller discrepancy between the observed and predicted values of salt content.

Table 1 – Parameters of mathematical models for salt content.

Model	Parameters	ST	UT-100	UT-300	UT-500	UT-700	SE	*P* value
Fick	D_s ($\times 10^{-7}$)	0.826^{d}	0.929^{d}	1.138^{c}	1.342^{b}	1.592^{a}	-	< 0.01
	%VAR	97.61	97.05	99.08	99.74	98.46	-	-
Peleg	$k_{s,1}$	43.706^{a}	38.579^{b}	30.963^{c}	25.785^{d}	21.638^{e}	1.852	< 0.01
	$k_{s,2}$	0.389^{a}	0.391^{a}	0.396^{a}	0.399^{a}	0.401^{a}	0.010	0.728
	R^2	0.986	0.987	0.994	0.996	0.993	-	-
	RMSE	0.084	0.081	0.054	0.048	0.064	-	-
Azuara	$k_{s,3}$	0.012^{d}	0.013^{d}	0.017^{c}	0.020^{b}	0.024^{a}	0.001	< 0.01
	R^2	0.975	0.977	0.986	0.989	0.986	-	-
	RMSE	0.112	0.107	0.084	0.078	0.087	-	-
Weibull	α	155.102^{a}	136.097^{b}	113.038^{c}	96.089^{d}	82.078^{e}	4.568	< 0.01
	β	0.764^{a}	0.795^{a}	0.775^{a}	0.766a	0.750^{a}	0.044	0.884
	R^2	0.990	0.991	0.997	0.999	0.996	-	-
	RMSE	0.072	0.069	0.040	0.029	0.045	-	-
Z and L	$k_{s,4}$	0.007^{d}	0.008^{d}	0.009^{c}	0.010^{b}	0.012^{a}	0.0004	< 0.01
	R^2	0.979	0.983	0.985	0.984	0.981	-	-
	RMSE	0.102	0.094	0.089	0.091	0.103	-	-

a-e indicate a significant difference between different groups ($P < 0.05$).

IV. CONCLUSION

In summary, the gradual enhancement of the NaCl diffusion coefficient after UT treatment suggested that ultrasound-assisted tumbling treatment could accelerate the salt diffusion into beef. Furthermore, Weibull is the best model for predicting the NaCl diffusion kinetics and is suitable for estimating NaCl content during ultrasound-assisted tumbling brining. Further research is worth exploring the 3D diffusion mechanism of NaCl during brining.

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REFERENCES

1. Jiang, F. Y., Zhang, J., Zhang, R. Y., Zhang, W. G. (2024). Effects of ultrasound-assisted vacuum tumbling on the flavor of spiced beef. Food Bioscience, 58, 103652.
2. Aykin-Dincer, E. (2021). Application of ultrasound-assisted vacuum impregnation for improving the diffusion of salt in beef cubes. Meat Science, 176, 108469.
3. Zhang, R. Y., Zhang, J., Zhou, L., Wang, L., Zhang, W. G. (2021). Influence of ultrasound-assisted tumbling on NaCl transport and the quality of pork. Ultrasonics Sonochemistry, 79, 105759.
4. Sanches, M. A. R., Paiva, G. B., Darros-Barbosa, R., Silva-Barretto, A. C. D., Telis-Romero, J. (2023). Mass transfer modeling during wet salting of caiman meat (*Caiman crocodilus yacare*) at different brine temperatures. Meat Science, 199, 109128.