Food Science of Animal Products

Research Article

Rapid pickling method of salted duck egg using alternating hot and cool conditions and ultrasonic treatment

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Abstract: Salted duck egg (SDE) is a traditional Chinese food. The traditional curing method needs a long period. To shorten the pickling process, ultrasonic power, ultrasonic time, and ultrasonic alternating temperature were employed as the single factor to produce SDE. The salt content of SDE white and yolk and texture, ultrasonic apparent oil yield rate of SDE yolk were selected as test index. The results showed that all three factors affected the quality of SDE to different degrees. The trend related to the change of salt content was in line with that of the apparent oil yield rate. The higher product quality and shorter pickling process were observed when treated with ultrasonic power of 240 W, ultrasonic time of 90 min, and heating/cooling time for 14 h/10 h. Suitable levels for three factors were set for the orthogonal experiment according to the results of the single-factor experiment. The results showed that the optimal experiment level was 240 W of ultrasonic treatment for 90 min at a time ratio of 14 h/10 h, shortening the pickling time to 18 d. Thus, this work established a faster physical pickling method for SDE. Ultrasonic treatment could improve the quality of products, and alternating temperature could provide a temperature pump to accelerate the pickling speed, which could be considered to assist the low-salt curing process.

Keywords: salted duck egg; ultrasonic; temperature alteration; rapid pickling

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1 Introduction

Salted duck egg (SDE), a traditional Chinese food, is a processed egg that is pickled in salt for about 30 d[1]. To ensure health, low salt curing is widely used in the production of SDE, which could produce SDE with high quality and long processing time[2]. For modern food manufacturers, shorter processing time means more profit. In many studies, different methods were employed to shorten the pickling time, including chemical and physical methods.

It was suggested that increasing the driving force of the mass transfer process and decreasing the mass transfer resistance could shorten the curing time of SDE[3]. When SDE was treated with high brine concentration, temperature and pulsed pressure, the driving force increased, and the curing speed was faster[4–7]. In consideration of the fragility of duck eggshells, high pressure or pulsed pressure technology was rarely investigated in SDE pickling in recent years. On the eggshell surface, there are thousands of pores, which are channels for water, air, and other extraneous substances[8–9]. At the early stage of the pickling process of Pidan, alkaline solution could remove the compact layer on the surface of duck eggshell, and expose the air holes, to promote the entrance of pickling solution[10]. Acid soaking could make the eggshell surface rough and porous, promoting the entrance of brine and inhibiting the generation rate of black circles (induced by the combined action of egg yolk proteins, Fe^{3+}, S^{2-} and pigments)[11–13]. When the eggshell surface become porous, the mass transfer resistance decreases, accelerating the curing process. Ultrasonic treatment decreased egg white viscosity[14], which also lowered the inner mass transfer resistance.

Other than the chemical methods, different physical methods were employed to accelerate the pickling process. For example, vacuum technology was used to shorten the produce cycle to 15 d, while was not easy to achieve continuous and mass production[13]. When treated with high-density ultrasonication (80 W), the salting time of the reduced-sodium SDEs was shorter than those of the traditional method[15–16]. In contrast with high pressure or pulsed pressure methods, vacuum curing caused differential pressure between the outer and inner parts of duck eggs, which induced deformation relaxation phenomena of the inner material, decreased the mass transfer resistance, and shortened the curing time[17–19]. However, ultrasonic-assisted curing was more beneficial in improving the water retention and tenderness of myofibrillar protein than the vacuum method[20–21]. Refrigerating temperature was commonly employed in egg storage and processing of egg products to keep their safety and quality[22–23]. While, low temperature will inhibit the oil elucidation, and high temperature will promote lipid oxidation[24]. It was demonstrated that when the pickling temperature was increased from 20 to 45 °C, the production cycle could be shorten by nearly 50%[25]. To accelerate the pickling process and prevent lipid oxidation, a proper temperature should be selected.

In this work, alternate heating and cooling and ultrasonic treatment were employed to produce SDE with less pickling time than the traditional method.

2 Materials and methods

2.1 Chemicals and reagents

Fresh duck eggs with green eggshells laid within 24 h were purchased from the education supermarket of the Henan University of Animal Husbandry and Economy, stored at 4 °C, and used for experiments within 30 d. Salt (Weiqun, Henan Salt Industry Group Co., Ltd.), high-alcohol Chinese Baijiu (53° Chinese liquor, Beijing Laobaigan, Beijing Chengjingliang Liquor Industry Co., Ltd.), and white vinegar (6°, HADAY, Foshan Haitian (Gaoming) Seasoning Food Co., Ltd.) were procured from Dennis supermarket (Zhengzhou, China).

2.2 Pickling process of SDE

The picking process of SDE was as follows: fresh duck eggs → checking (candling) → selecting eggs without cracks and cleaning → soaking in white vinegar (3%, *m*/*m*) for 20 min → canning → filling in brine with 24 g/100 mL salt and 3% high-alcohol Chinese Baijiu → ultrasonic treatment → curing → sampling and testing every 5 d from day 7 or day 10.

All the duck eggs were divided into 15 groups (5 ultrasonic power groups, 5 ultrasonic time groups, and 5 temperature alternating groups) with 12 eggs in each group. In the ultrasonic-assisted group, the ultrasonication frequency was 22 kHz, and the operation was conducted once daily from day 1 to day 3.

2.3 Analysis of ultrasonic treatment on pickling speed and quality of SDE

After soaking in white vinegar, duck eggs were immersed in brine and treated using ultrasonication (WKS 900B/3S, Jiangsu Jiangda Wuzisong Biotechnology Co., Ltd.) at different powers (0, 60, 120, 180, and 240 W) and times (0, 60, 90, 120, and 150 min in total, or 0, 20, 30, 40, and 50 min thrice). When the ultrasonic process was completed, the duck eggs were stored at 40 °C until ripened. As the ultrasonic time experiment required 3 d and taking account of the actual workload, the eggs in the ultrasonic power experiment were sampled on day 7, while that of the ultrasonic time experiment were sampled on day 10. The sampling frequency was once every 5 d.

2.4 Analysis of alternate heating and cooling conditions on pickling speed and quality of SDE

After soaking in white vinegar, duck eggs were immersed in brine and treated with ultrasonication at 120 W for 40 min. The curing temperature was set at 40 °C in constant temperature drying box (DHG-2080B, Shanghai Fuma Laboratory Instrument Co., Ltd.) and 5 °C in refrigerator (BCD-248WBSV, Qingdao Haier Co., Ltd.) for the hot and cool conditions, respectively. The time of heating/cooling was set at 8 h/16 h, 10 h/14 h, 12 h/12 h, 14 h/10 h, and 16 h/8 h until ripened. The samples were taken out from day 10 and detected every 5 d.

2.5 Detection of salt content

The salt content of samples (SDE white and SDE yolk) was detected using the digital salt meter (ES-421, Tokyo, Japan) according to the method of Wang et al.[7]. The samples were ground evenly, and then 5 g of the sample was weighed accurately (accurate to 0.000 1 g) and placed in a 50 mL colorimetric tube with a stopper. Next, 25 mL of hot distilled water (70 °C) was added into the colorimetric tube, shaken for 2 min to mix the sample, ultrasonicated for 20 min with ultrasonic power of 180 W, cooled to room temperature, added water to make up the volume, shaken, and filtered. The remaining mixture above filter paper was sampled using the digital salt meter to detect the salt content. Each test was replicated three times.

2.6 Detection of apparent oil yield rate

The apparent oil yield rate of SDE yolk was detected according to the methods of Wang et al.[26] and Ai et al.[27]. Four pieces of 7 cm qualitative filter papers were dried at 105 °C to constant weight and named m_1 (g). The cooked SDE yolk was stirred into even small pieces and named m_2 (g). After oil absorption, the weight of oil-absorbing filter papers was measured as m_3 (g). Each test was replicated three times. The apparent oil yield rate was calculated as follows:

$$\text{Apparent oil yield rate (\%)} = \frac{m_3 - m_1}{m_2} \times 100$$

2.7 Texture profile analysis (TPA)

The TPA of cooked SDE white and yolk were accomplished according to the method of Wu et al.[21]. SDE white was cut into 10 mm × 10 mm × 8 mm sizes, and the SDE yolk was cut in half. Each test was replicated six times. The texture analyzer (CT3 10k, Brookfield, USA) was employed to conduct the TPA. TA11/1000 cylindrical probe (25.4 mm) was selected to detect hardness (g), cohesiveness, springiness (mm), and chewiness (mJ) of samples at a speed of 2.0 mm/s. For the SDE white, the compression ratio was 50%, and the trigger point load was 5 g. For the SDE yolk, the compression ratio was 30%, and the trigger point load was 3 g.

2.8 Statistical analysis

At least three replicates were prepared for all the measurements. The results of separation and chemical analysis were subjected to Duncan's multiple range test using SPSS 16.0 (IBM SPSS Inc.). The confidence intervals were set at 95% (P < 0.05). Origin 2021b and Adobe Illustrator CS 6 were employed to draw graphs.

3 Results and discussion

3.1 Effect of ultrasonic treatment and temperature alternation on the pickling speed of SDE

When treated with 0–240 W for 0–150 min using ultrasonication, the pickling speed of SDE changed (Figures 1A–D). The results showed that the salt content of SDE white and yolk increased with the increase in ultrasonic power, and the 240 W ultrasonic treatment presented the highest salt content in both the white and yolk, inducing faster pickling speed. Ultrasonic treatment could induce cavitation, causing a larger surface area for calcium nanoparticles and making salt osmosis easier from the outside to the inside of the eggshell[28]. In addition, the ultrasonic treatment could improve the surface hydrophobicity of protein, increase the hydration capacity, and promote salt diffusion in SDE white and yolk[20,29]. Higher ultrasonic power can produce stronger cavitation [30].

As shown in Figures 1C and D, the optimal ultrasonic time was 90 min, and the curing speed decreased with longer ultrasonic treatment. It was demonstrated that ultrasonic treatment might cause protein aggregation[31]. In this experiment, when the duration

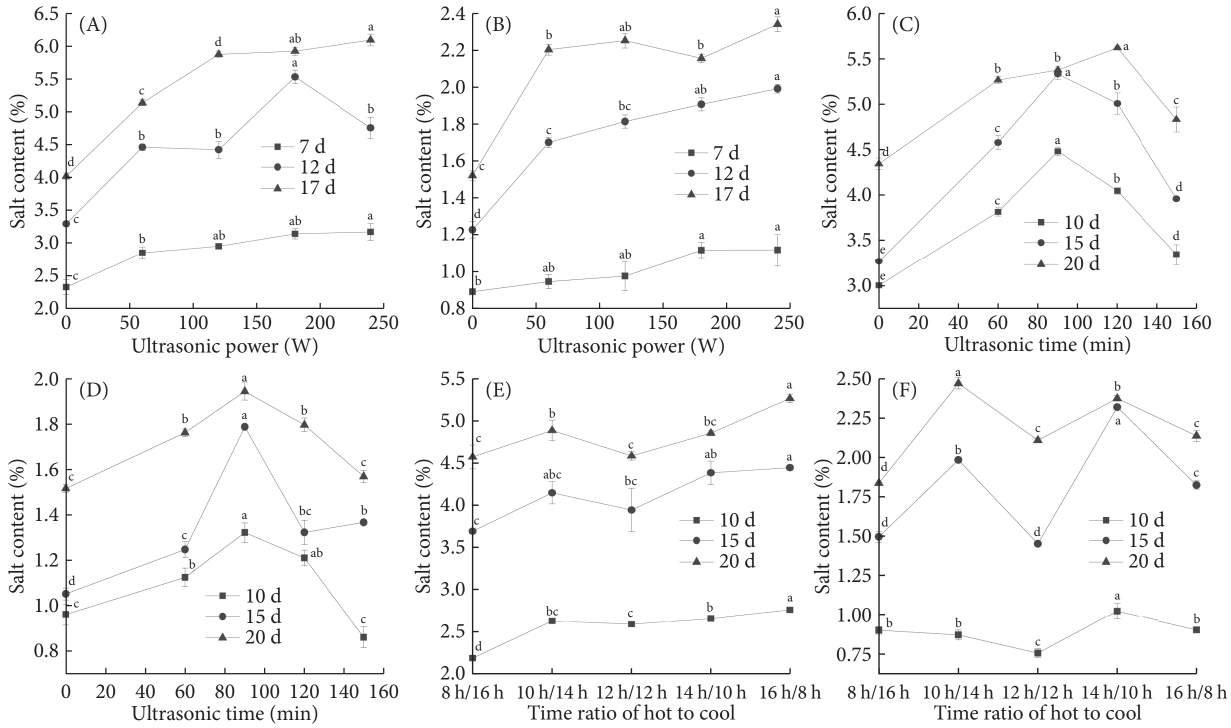

Figure 1 Effect of different treatments on the salt content of SDE white and yolk. (A) Ultrasonic power on SDE white; (B) ultrasonic power on SDE yolk; (C) ultrasonic time on SDE white; (D) ultrasonic time on SDE yolk; (E) temperature alteration on SDE white; (F) temperature alteration on SDE yolk. Above each line, different lowercase letters mean significant variation among different treatment levels ($P < 0.05$).

of ultrasonic treatment was longer than 90 min, extreme protein aggregation appeared, and the curing speed decreased.

When the pickling temperature changed, the speed changed as well. A higher pickling temperature could shorten the process[25,32], while a lower temperature could preserve eggs maximally; for example, by lowering lipid oxidation level[33] and resulting in the better freshness of products[13]. Moreover, as shown in Figures 1E and F, a faster pickling process occurred when the time ratio of hot to cool conditions was 14 h/10 h.

In conclusion, an ultrasonic treatment at appropriate power and time and a specific ratio of heating/cooling time could significantly increase the curing speed.

3.2 Effect of different treatments on the texture of SDE yolk

When processed with different treatments, the texture of SDE changed correspondingly in hardness and chewiness, while the cohesion and springiness didn't show significant difference among the three treatments (Figure 2). During the pickling process, the final hardness and chewiness of SDE decreased significantly ($P < 0.05$) with the increase in ultrasonic power (Figures 2A and D). This might induce a congealed structure of cooked egg yolk, offering space for the increasing flowing oil to fill and collapse the gel network to form a distinctive loss in texture[34]. Furthermore, a continuous ultrasonic treatment might destroy the structure of the shell and vitelline membranes, causing dehydration. As shown in Figures 2E and H, 120 min of ultrasonic treatment significantly decreased the hardness and chewiness of SDE yolk ($P < 0.05$); thus, it could be selected as the determined level of the orthogonal test. However, the final hardness and chewiness were higher than the ultrasonic-treated groups at different powers, which could be attributed to the protein aggregation due to the long duration of ultrasonic treatment[31]. It was reported that the salting process could cause a pronounced dehydration phenomenon, leading to a closer granule structure and harder yolk texture[29]. When the temperature was altered (Figures 2J and L), the low temperature slowed down this process and produced a softer cooked yolk.

3.3 Effect of different treatments on apparent oil yield rate of SDE yolk

The salting treatment induces oil elucidation of exterior yolk[29]. It was reported that salt could break down the lipoprotein, causing the yolk particles to become increasingly compact to extrude oil and forming the sandy and oil quality of SDE yolk[35]. As shown in Figure 3, in different curing stages, the apparent oil yield rate increased significantly with the increase in ultrasonic power ($P < 0.05$) and reached a peak value around a 90 min ultrasonic treatment ($P < 0.05$). When treated with alternating temperature conditions, the oil yield rate was higher than the other two groups, and the highest oil yield was harvested when the time ratio of hot to cool was 14 h/10 h. Overall, the results of the three treatments with regard to apparent oil yield were in accordance with those of the salt content, which proved that higher salt content and apparent oil yield rate could mean a faster pickling process.

3.4 Orthogonal experiment

Based on the three single-factor experiments results, suitable factor levels were selected for the orthogonal experiment: 180, 240, and 300 W for ultrasonic power; 90, 105, and 120 min for ultrasonic time; 10 h/14 h, 14 h/10 h, and 16 h/8 h for time ratio of hot/cool conditions (Table 1). The results and range analysis were shown in Table 2, and the variance analysis was shown in Table 3.

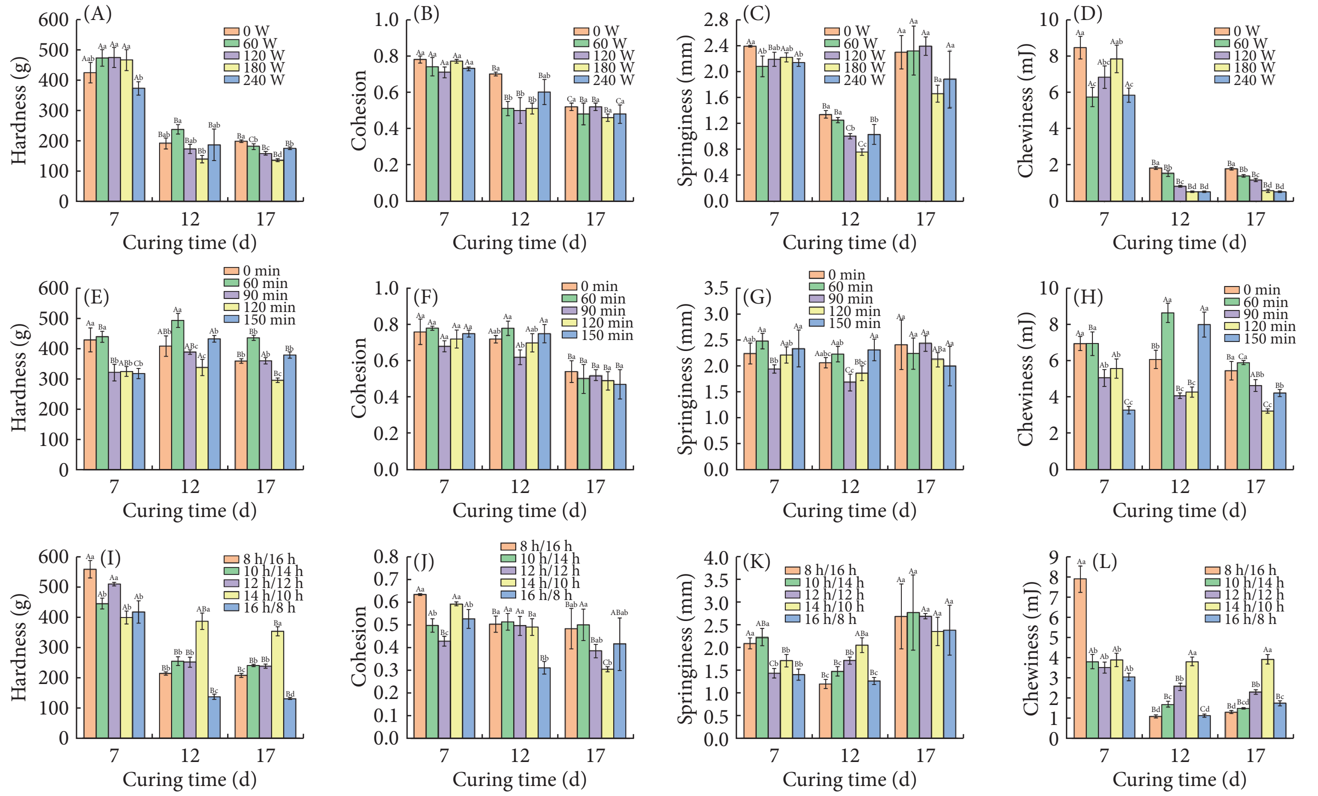

Figure 2 Effect of different treatments on the texture of SDE yolk. (A–D) Hardness, cohesion, springiness, and chewiness at different ultrasonic powers, respectively. (E–H) Hardness, cohesion, springiness, and chewiness at different ultrasonic time, respectively. (I–L) Hardness, cohesion, springiness, and chewiness at alternating temperature conditions, respectively. Above each bar, different lowercase letters mean significant variation among different treatment groups (P < 0.05), different capital letters mean significant variation among different pickling time groups (P < 0.05)

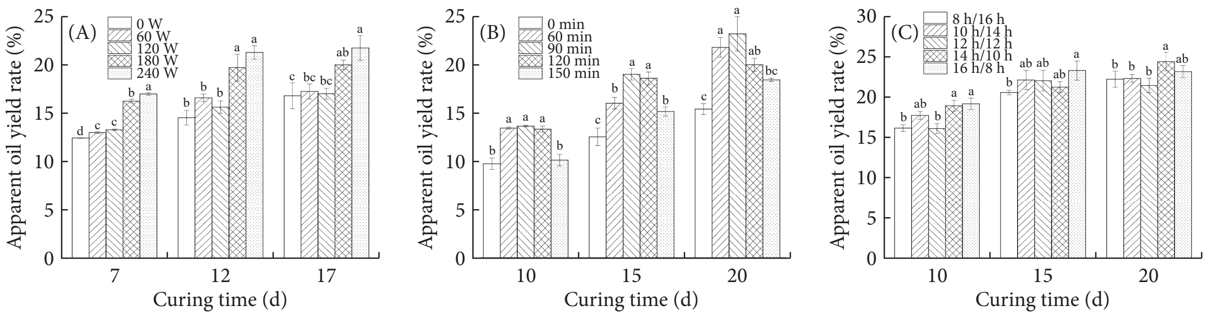

Figure 3 Effect of different treatments on apparent oil yield rate of SDE yolk. (A) Ultrasonic power; (B) ultrasonic time; (C) time ratio of hot/cool conditions. Above each bar, different lowercase letters mean significant variation among different treatment levels (P < 0.05).

Table 1 Factors and levels of orthogonal experimental.

Level	A Ultrasonic power (W)	B Ultrasonic time (min)	C Time ratio of hot/cool conditions (h)
1	180	90	10/14
2	240	105	14/10
3	300	120	16/8

The results of the orthogonal experiment showed that the final salt content of SDE yolk was highest in experiment No.4, and the final apparent oil yield rate was highest in experiment No.3. To compare the importance of different factors on different indexes, the range analysis was conducted. Through the analysis of the quality of salted duck egg, it is confirmed that mature salted duck egg can be obtained after 18 d of curing cycle. At 18 d (Table 2), the order was $A > B > C$ for the salt content of SDE white, $C > A > B$ for the salt content of SDE yolk, and $C > A > B$ for apparent oil

Table 2 Result of orthogonal experimental.

No.	A	B	C	Salt content of SDE white (%)	Salt content of SDE yolk (%)	Apparent oil yield rate (%)
1	1	1	1	6.09	1.18	16.84
2	1	2	2	6.46	1.16	20.78
3	1	3	3	7.09	1.38	24.21
4	2	1	2	7.94	2.77	22.19
5	2	2	3	7.63	1.34	16.09
6	2	3	1	6.62	1.17	16.27
7	3	1	3	7.77	1.14	20.44
8	3	2	1	8.57	1.72	18.01
9	3	3	2	7.66	2.14	21.05
R_1	1.45	0.43	0.41			
R_2	0.52	0.29	0.74			
R_3	2.43	2.22	4.30			

yield rate. The variance analysis of the 18 d experiment showed that all three factors affected all three indexes significantly (Table 3), except ultrasonic power for SDE yolk (P = 0.088). A comprehensive consideration of the results, range and variance analyses of the orthogonal experiment were processed, and 240 W ultrasonic treatment for 90 min at a time ratio of 14 h/10 h was selected as the optimal pickling condition for SDE process.

Table 3 Variance analysis of orthogonal experiment results.

Factor	Index	P	Significance
	Salt content of SDE white	0.000	**
A	Salt content of SDE yolk	0.088	NS
	Apparent oil yield rate	0.015	*
	Salt content of SDE white	0.046	*
B	Salt content of SDE yolk	0.008	**
	Apparent oil yield rate	0.001	**
	Salt content of SDE white	0.001	**
C	Salt content of SDE yolk	0.000	**
	Apparent oil yield rate	0.002	**

Note: Duncan analysis at a 95% confidence interval (P < 0.05). * P < 0.05; ** P < 0.01; NS indicates no significant difference.

The optimized pickling condition for SDE process was repeated. The results showed that a ripe SDE could be produced after 18 d of pickling, which was not observed using the traditional curing method (Figure 4).

(A) (B)

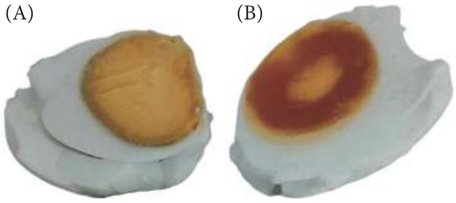

Figure 4 Products pickled using (A) the traditional method and (B) the optimized experimental conditions.

4 Conclusion

SDE is a traditional Chinese food and popular among consumers. In this work, ultrasonic power, ultrasonic time, and alternating temperature conditions were employed to accelerate the pickling process of SDE.

First, a single-factor experiment was conducted with the salt content of SDE white and yolk and texture and the apparent oil yield rate of SDE yolk as the test index. All three factors affected the quality of SDE noticeably. The higher the ultrasonic power employed, the higher the salt content found in SDE white and yolk, the lower the hardness and chewiness of SDE yolk obtained, and the higher the apparent oil yield rate acquired, which implied a faster pickling speed and a better product quality. When the ultrasonic time changed, the opposite trend of salt content and apparent oil yield rate on either side of 90 min was observed. The pickling temperature altered between 40 and 5 °C every 24 h. The highest salt content and apparent oil yield rate of SDE yolk were detected at a time ratio of 14 h/10 h. It was identified that the trend related to changes in the salt content was in line with that of apparent oil yield rate.

According to the results of the single-factor experiment, an ultrasonic power of 240 W, ultrasonic time of 90 min, and alternating temperature conditions for 14 h/10 h were selected as reference levels for the orthogonal experiment. The quality of SDEs was investigated during the curing process. It was found that 18 d was enough to produce ripe SDEs for some experiments. After a comprehensive judgment from the salt content and apparent oil yield rate at 18 d, an ultrasonic treatment of 240 W for 90 min at a time ratio of 14 h/10 h was selected as the optimal experiment level, which was in agreement with the results of single-factor experiment.

This work created a faster pickling technology for SDE. On the one side, ultrasonic treatment could improve the quality of products. On the other side, alternating temperature could provide a temperature pump to accelerate the pickling speed. This work could be considered to assist the low-salt curing process. To realize the industrialize of this pickling technology of SDE, more specific research work needs to be conducted.

Conflict of interests

The authors declare that there is no conflict of interest.

Ethical approval

Ethical approval was not required as the study did not involve any human or animal testing.

References

[1] Y. Liu, J. Chen, B. Zou, et al., Evaluation of the quality and flavor of salted duck eggs with partial replacement of NaCl by non-sodium metal salts, LWT-Food Sci. Technol. 172 (2022) 114206. https://doi.org/10.1016/j.lwt.2022.114206.

[2] Z. Ligen, W. Qian, W. Liping, et al., Quality evaluation and lipidomics analysis of salted duck egg yolk under low-salt pickling process, Food Chem.: X 16 (2022) 100502. https://doi.org/10.1016/j.fochx.2022.100502.

[3] Y. Zhang, Research on mass transfer characteristics of duck eggshells, Huazhong Agricultural University, Wuhan, 2013. https://doi.org/10.7666/d.Y2394594.

[4] Q. Xu, X. Li, X. Xiao, et al., Effects of salting conditions on the morphology and composition of cooked salted duck eggs yolk, Sci. Technol. Food Ind. 44(11) (2023) 80–87. https://doi.org/10.13386/j.issn1002-0306.2022060301.

[5] S. M. Razi, A. Motamedzadegan, L. Matia-Merino, et al., The effect of pH and high-pressure processing (HPP) on the rheological properties of egg white albumin and basil seed gum mixtures, Food Hydrocoll. 94 (2019) 399–410. https://doi.org/10.1016/j.foodhyd.2019.03.029.

[6] J. Zhang, M. Zielinska, H. Wang, et al., Simulation of fluid flow during egg pickling under different inlet and outlet conditions in a pulsed pressure tank with liquid circulation, Foods 11 (2022) 2630. https://doi.org/10.3390/foods11172630.

[7] X. Wang, Z. Gao, H. Xiao, et al., Enhanced mass transfer of osmotic dehydration and changes in microstructure of pickled salted egg under pulsed pressure, J. Food Eng. 117 (2013) 141–150. https://doi.org/10.1016/j.jfoodeng.2013.02.013.

[8] A. Riley, C. J. Sturrock, S. J. Mooney, et al., Quantification of eggshell microstructure using X-ray micro computed tomography, Br. Poult. 55 (2014) 311–320. https://doi.org/10.1080/00071668.2014.924093.

[9] M. T. Hincke, O. Wellman-Labadie, M. D. McKee, et al., Biosynthesis and structural assembly of eggshell components, in: Y. Mine (Eds.), Egg bioscience and biotechnology, John Wiley & Sons, Inc., New Jersey, 2008, pp. 97–128. https://doi.org/10.1002/9780470181249.ch2.

[10] X. Ruan, The influence of alkali on egg shell and gel mechanism of duck egg white, Huazhong Agricultural University, Wuhan, 2014. https://doi.org/10.7666/d.Y2565728.

[11] J. Sun, J. Du, H. Yang, et al., Effect of acid curing agent on salted egg, Food Sci. Technol. 46 (2021) 45–50. https://doi.org/10.13684/j.cnki.spkj.2021.04.007.

[12] Q. Li, H. Liu, Y. Li, et al., Analysis of the causes of the "Black Circles" in the vacuum cooked salted duck eggs, Modern Food Sci. Technol. 37 (2021) 234–241. https://doi.org/10.13982/j.mfst.1673-9078.2021.9.0032.

[13] L. Tan, M. Zheng, S. Chen, et al., Changes in physicochemical properties, molecular structure and microstructure during vacuum assisted quick pickling of low-NaCl salted eggs, LWT-Food Sci. Technol. 189 (2023) 115480. https://doi.org/10.1016/j.lwt.2023.115480.

[14] G. Li, Y. Zhao, J. Wang, et al., Effect of ultrasonic treatment on protein structure and physicochemical and foaming properties of liquid egg white, Food Sci. 40 (2019) 68–75. https://doi.org/10.7506/spkx1002-6630-20180419-248.

[15] Z. Yu, H. Guo, C. Liu, et al., Ultrasound accelerates pickling of reduced-sodium salted duck eggs: an insight into the effect on physicochemical, textural and structural properties, Food Res. Int. 156 (2022) 111318. https://doi.org/10.1016/j.foodres.2022.111318.

[16] X. Sun, L. He, H. Yang, et al., Intermittent ultrasound assisted in speeding up the pickling speed of salted eggs, Sci. Technol. Food Ind. 39 (2018) 204–211. https://doi.org/10.13386/j.issn1002-0306.2018.22.036.

[17] J. Mao, L. Zhang, F. Chen, et al., Effect of vacuum impregnation combined with calcium lactate on the firmness and polysaccharide morphology of kyoho grapes (*Vitis vinifera* × *V. labrusca*), Food Bioprocess Tech. 10 (2017) 699–709. https://doi.org/10.1007/s11947-016-1852-5.

[18] N. Sun, H. Liu, Y. Wen, et al., Comparative study on Tianjin and Baiyangdian preserved eggs pickled by vacuum technology, J. Food Process. Pres. 44(4) (2020) e14405. https://doi.org/10.1111/jfpp.14405.

[19] Y. Chen, P. Zheng, H. Liu, et al., Changes in physiochemical properties of egg white during vacuum curing of salted eggs, Food Res. Development 43 (2022) 6–13. https://doi.org/10.12161/j.issn.1005-6521.2022.03.002.

[20] Z. Gao, D. Wu, H. Wang, et al., Effects of curing process on myofibrillar protein characteristics and water distribution of beef, Food Ferment. Ind. 47 (2021) 179–186. https://doi.org/10.13995/j.cnki.11-1802/ts.027285.

[21] Y. Wu, X. Xiang, X. Li, et al., Study on the mechanism of improving the quality of salted egg yolks by ultrasonic synergistic NaCl dry-curing, Ultrason. Sonochem. 102 (2024) 106746. https://doi.org/10.1016/j.ultsonch.2023.106746.

[22] M. H. Lee, E. J. Cho, E. S. Choi, et al., The effect of storage period and temperature on egg quality in commercial eggs, Korean J. Poult. Sci. 43 (2016) 31–38. https://doi.org/10.5536/KJPS.2016.43.1.31.

[23] Y. Yang, D. J. Geveke, B. A. Niemira, Quality of radio frequency pasteurized shell eggs during extended storage under normal and moderate abuse conditions, Food Control 116 (2020) 107330. https://doi.org/10.1016/j.foodcont.2020.107330.

[24] M. Long, Y. Song, Q. Du, et al., Effect of pickling temperature and concentration of salt solution on lipid of duck egg yolk, Transactions of the Chinese Society of Agricultural Engineering 31 (2015) 281–288. https://doi.org/10.11975/j.issn.1002-6819.2015.18.038.

[25] J. Sun, Y. Wu, Q. Zeng, et al., High temperature curing softening salted egg yolk: insights on microstructure, texture properties and composition of key protein, LWT-Food Sci. Technol. 201 (2024) 116237. https://doi.org/10.1016/j.lwt.2024.116237.

[26] Z. Wang, Y. Rao, C. Dai, et al., Quality analysis and grading standards of cooked salted duck egg, Chinese Agr. Sci. Bull. 33 (2017) 123–128.

[27] M. M. Ai, S. G. Guo, Q. Zhou, et al., The investigation of the changes in physicochemical, texture and rheological characteristics of salted duck egg yolk during salting, LWT-Food Sci Technol. 88 (2018) 119–125. https://doi.org/10.1016/j.lwt.2017.10.013.

[28] P. E. Liew, B. Shanmugarajaha, I. M. L. Chew, et al., Ultrasound assisted extraction of nano calcium from waste eggshell: a preliminary study on crystal violet dye removal. in Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (PRES), Kuching, Malaysia, 2015. https://doi.org/10.3303/cet1545286.

[29] X. Li, S. Chen, Y. Yao, et al., The quality characteristics formation and control of salted eggs: a review, Foods 11 (2022) 2949. https://doi.org/10.3390/foods11192949.

[30] Z. Lü, R. Hou, Z. Zhang, et al., Effect of ultrasonic vibration on cavitation erosion of aluminum oxide in fluid jet machining, Int. J. Adv. Manufact. Technol. 111 (2020) 2911–2918. https://doi.org/10.1007/s00170-020-06275-w.

[31] Y. Xie, J. Wang, Y. Shi, et al., Molecular aggregation and property changes of egg yolk low-density lipoprotein induced by ethanol and high-density ultrasound, Ultrason. Sonochem. 63 (2020) 104933. https://doi.org/10.1016/j.ultsonch.2019.104933.

[32] Y. Huang, S. Xian, J. Du, et al., Comparison of qualities of Hami melon fruitlet pickles made at different temperatures and fermentation methods, J. Northeast Agr. Univ. 52 (2021) 56–66. https://doi.org/10.19720/j.cnki.issn.1005-9369.2021.11.007.

[33] Y. Chen, H. Li, H. Tang, et al., Preparation and storage stability of docosahexaenoic acid enriched egg yolk powder, Acta Agr. Zhejiangensis 32 (2020) 2226–2231. https://doi.org/10.3969/j.issn.1004-1524.2020.12.14.

[34] X. Wang, Y. Huang, B. Zhou, et al., Improvement of quality and flavor of salted egg yolks by ultrasonic assisted cooking, Ultrason. Sonochem. 75 (2021). https://doi.org/10.1016/j.ultsonch.2021.105579.

[35] Z. Bao, D. Kang, C. Li, et al., Effect of salting on the water migration, physicochemical and textural characteristics, and microstructure of quail eggs, LWT-Food Sci. Technol. 132 (2020) 109847. https://doi.org/10.1016/j.lwt.2020.109847.