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STUDY ON THE EFFECT OF BAKING PROCESS ON THE QUALITY CHARACTERISTICS, MOISTURE DISTRIBUTION AND SENSORY EVALUATION OF BRAN, DUCK AND PORK EMULSIFICATION SAUSAGE

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Poultry sausage is a low-fat, protein-friendly product, and the research on poultry sausage has gradually become a hot field of meat product research. The baking process can promote the decomposition of protein and fat, and the Maillard reaction occurs, thereby increasing the color of the sausage and improving the flavor of the sausage. Baking time affects cooking loss, color, pH, TPA, moisture distribution and sensory evaluation results of cooked sausage products, therefore, the baking process is very important. In this study, four baking treatment experiments of 40, 60, 80 and 100 min were set up, the baking temperature was 60 °C.

The 60min treatment group had the smallest brightness value L, the highest redness value a, and the best color. The water content of the 40 min treatment group was the highest, followed by the 80 min treatment group, and the pH value of the other 80 min treatment group was also the lowest. In terms of TPA and water distribution, the hardness value of the 60 min treatment group was the highest, and the relaxation times (T2) corresponding to hydrated water, fixed water and free water were 0.1–9.3 ms, 10–91 ms, and 175–900 ms, respectively, and the 80 min treatment group The group with the most semi-bound water worked best. In terms of sensory evaluation, the color, flavor, texture, and overall acceptability of the 60 80 min treatment groups were not significantly different. The best evaluation result was the 100 min treatment group, followed by the 60 and 80 treatment groups. Based on the above research results of sausage quality, the optimal baking time of sausage in this study is 60–80 min. This research can provide product quality data and technical support for the development of duck and pork compound sausages

Keywords: sausage, quality characteristics, TPA, moisture distribution, sensory evaluation, cooking technology

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1. Introduction

As an important part of a balanced diet, meat products provide the human body with high-quality animal protein and some important minerals, vitamins, etc., and occupy a large proportion of people's dietary structure. Emulsified sausage is a special minced meat product. It is a dispersion system formed by chopped lean meat, fat, water, salt and other additives at low temperature and high speed. The salt-soluble protein precipitated in the chopping process is used as the emulsifier, wrapped in small fat particles, so that the product system reaches a uniform and stable state [1]. The fat content of emulsified sausage is usually about 20~30 %, which is widely welcomed by consumers because of its rich nutrition and unique taste.

In the production process of emulsified sausage, the myofibrillar protein in the minced meat is dissolved through the chopping step, and the proteins interact with each other to form a gel network during the heating process, and the water is retained in the minced meat through protein binding and capillary action [2]. However, reports of diabetes, cardiovascular disease, obesity and other chronic diseases related to fat intake are gradually increasing in the world [3, 4].

In order to prevent these diseases, more and more attention has been paid to the research on functional sausages with balanced nutrition and alleviation of diseases.

Therefore, research low-salt, low-fat emulsified sausages to meet the needs of physical health.

Duck meat is rich in nutrients and is a high-protein, low-fat food, with a protein content of 18 % and a fat content of 25 % to 30 %. It also contains a variety of trace elements and B vitamins [5, 6], which can effectively resist beriberi and A variety of inflammation, but also anti-aging, it is rich in niacin, which has preventive and protective effects on heart diseases such as myocardial infarction [5]. Some studies [7] showed that the processing performance of duck meat was poorer than that of other raw meat. The study found that the processing characteristics of chicken and duck were significantly different, and the performance of minced meat gel was also significantly different. The overall processing quality of chicken was better than that of duck. Compared with duck meat, chicken minced meat has a higher protein content, and the higher protein content is more favorable for the dissolution and dissolution of myofibrillar proteins, which can make the protein between the meat minced form a better network gel structure. The better gel structure of meat emulsion can improve the water retention and cooking yield of meat emulsion, and increase the hardness and elastic recovery of cooked meat emulsion. This also results in the low utilization rate of duck meat products compared with more mature pork and beef products, and the waste of minced duck meat is more serious, resulting in far less development efforts and insufficient product types. In addition, in the market, the price of duck breast meat and chicken breast meat is about 3 USD/kg, but the market time of broiler chicken is 45–60 days while that of meat duck is only 30–35 days, and the production efficiency of meat duck is 1.5 times that of broiler chicken. Therefore, it is very necessary to develop duck meat products.

In order to improve the quality of sausage and increase its flavor and nutritional functionality, researchers have tried to add various plant ingredients to emulsified sausage products, most of which are fruits and vegetables, edible fungi, and grains. Phenolic substances, vitamins and organic acids present in natural plants have excellent antioxidant functions [8], and their extremely high dietary fiber content can improve the quality characteristics of meat products. Plants with unique aromas and colors can also enrich the nutritional and organoleptic qualities of sausages.

Dietary fiber has the properties of emulsifying, water-holding, and foam-holding. Higher water-holding capacity can significantly improve the water-holding capacity of sausage, increase the viscosity of food, and endow food with good sensory properties and texture quality. However, it is also difficult to add dietary fiber to sausage. When the amount of dietary fiber added is not suitable, the sausage may have problems such as dry structure and rough taste; use dietary fiber to replace fat [9], may also reduce product tenderness, juiciness, and water retention.

The research of adding plant dietary fiber to sausage is mainly concentrated in the field of pork sausage. [10] added pig skin and wheat fiber to sausage to replace fat. The hydration of dietary fiber and protein significantly increased the moisture and protein content of sausage, and improved the texture quality of sausage. Therefore, adding bran dietary fiber to sausage can better improve the nutritional composition of sausage.

In addition to changing the composition of meat raw materials and adding plant dietary fiber、food additives, the heating process is also an important factor affecting the quality of sausages. The heating will trigger a series of physical and chemical reactions in minced meat, such as texture changes, Carbonyl ammonia reaction, flavor formation, etc., and it can also kill pathogens and ensure the safety of meat products [11]. During thermal processing, the most important change in the meat emulsion system is the gelation reaction, that is, the change of muscle protein molecules to form heat-induced gels by thermal denaturation [12]. The minced meat thermal gel system can stabilize evenly distributed fat particles and water, which has a significant impact on product quality, taste, emulsification and water retention. Changes in temperature can cause changes in protein structure, denaturation, decomposition or aggregation of protein molecules, thus affecting the oxidative stability of minced meat [13]. When the meat emulsion of the emulsified system is heated, it will become a gel system. Heating process is commonly used in fermented sausages, such as smoked sausage, Chinese Cantonese sausage and Sichuan bacon, etc., but the application of baking process to emulsifying cooked sausage is rarely studied.

The addition and application of plant raw materials in sausages has been widely concerned. At the same time, the plant material affects the quality of the sausage. The improvement of sausage quality can be achieved by adding product quality improvers or changing the production process. Little attention has been paid to the changes in physical and chemical properties of sausages brought about by the barking process. It is desirable: the task of the research is to develop a technology using meat, so that it can be better used in sausage production.

2. Literature review and problem statement

Wheat bran is an important by-product of the milling process of wheat flour. Data from Chinese laboratories have showed that wheat bran was rich in dietary fiber (31.4 %) and protein (18 %), with a fat content of only 0.6 % [14]. The source of bran is very wide, and the bran has a very good application prospect as the raw material of sausage.

Under certain feeding technologies, ducks have an undesirable fishy smell. Therefore, the fishy smell of duck meat has an adverse effect on the flavor of sausage products, and the use of duck meat to process sausage products will affect the flavor of the product.

There is a study [15] removing duck skin and replacing duck fat with pig fat can give the product a rich flavor. This indicates that duck skin is the main source of the fishy smell of duck sausage. In terms of duck sausage research, the previous study showed that adding 2 parts of duck meat and 8 parts of pork, chopping and mixing time of 6 minutes, and cooking time of 25 minutes, can obtain Western-style sausage products with the best texture properties and quality[16]. Further proof that the use of pig fat instead of duck fat in duck sausage is better. Scientists reported that they made a convenient duck sausage with unique flavor using the ratio of pig fat and duck meat at 20:80 [15]. Besides, it has been shown that using the optimal ratio of Lactobacillus casei and Staphylococcus xylosus to be 1:1, the fermentation temperature was 15 °C, and the inoculation amount was 5 %, which can remove the fishy smell and obtain better flavor and taste of duck sausage [17]. At present, there are many reports using pork and chicken to make sausages and compound meats to make sausages, but there are still relatively few reports of using duck meat to make sausages. This is why this study chose duck breast instead of pork and still used pig back fat as the raw material.

Heat is used to promote gel formation. The change of rheological properties of minced meat is affected by the heating temperature. The intermolecular chemical forces, protein conformation, and water distribution and migration of minced meat are closely related to gelation during heating. It can reflect the structural characteristics of protein molecules during gel formation [18]. In China, the Cantonese-style sausage processing technology often uses hot air drying to make sausages. It is not a simple dehydration and drying process. It involves various reactions that affect the quality of Cantonese-style sausages such as flavor, color and texture [19]. In addition, studies have shown that the best quality sausage was obtained by baking at a temperature of 60 °C and a baking time of 30 hours [20]. The best technological conditions for preparing duck sausage by mixed bacteria fermentation of Lactobacillus sake and Pediococcus lactis were the ratio of strains of 2:1, the inoculation amount was 5 mL/kg, the fermentation temperature was 35 °C, the fermentation time was 20.3 h, the baking temperature was 76 °C, and the baking time was 5.4 h [21]. Many countries use fruit wood to smoke and heat the sausage to obtain a rich taste [22, 23]. The results of previous studies fully demonstrate that heating can improve the flavor and quality of sausage products. All this suggests that it is advisable to conduct a study on the effect of baking time on the quality of sausages.

Bran, duck, and pork were used as raw materials to make sausages in this study. By changing the baking time, the cooking loss, texture changes, sensory and other characteristics of sausages were analyzed to obtain the best baking time for sausages. In the process of emulsified sausage, setting the baking process to improve the sausage quality is a simple and effective way. It provides some theoretical basis for its further application.

3. The aim and objectives of the study

The aim of the study is to effect different baking time on the quality of bran-duck-pork emulsified sausage, improve sausage texture characteristics and increase sausage flavor. This may make the roasting process an indispensable link in the processing of emulsified sausages.

To achieve this aim, the following objectives are accomplished:

– to determine cooking loss, emulsion stability, color, moisture content, pH of baked sausages;

– to determine the texture properties of baked sausages;

– to determine the distribution of water of baked sausages;

– to determine the sensory evaluation of baked sausages.

4. Materials and Methods

In this study, Wheat bran (Henan Jinyuan Grain & Oil Company, Zhengzhou, China, 18 % protein, 0.6 % fat, 31.4 % dietary fiber) was crushed and sifted (part below 80 mesh). Lean and Duck breast pre-cold and processed by meat grinder (mince plate diameter 8 mm). Chinese white wine (Sanhua Rice Wine, Guilin Sanhua Co., Guilin, China). Spices and peper (Wang Shouyi Shi san Xiang Co., Zhumadian, China). Complex phosphate (Harsen Foods (Hongkong) Co.,LTD, Shantou,China, Sodium pyrophosphate 60 %, sodium tripolyphosphate 39 %, sodium hexametaphosphate 1 %). Sausage ingredients include: 300 g lean pork, 200 g duck breast, 6 g bran, 100 g ice water, 7 g salt, 1 g compound phosphate, 4 g spices, 1 g pepper, 20 g rice wine, 1g red yeast rice. The sausage ingredients were chopped and put into the pig's small intestine. The meat batters were heated at 75 °C for 30 min in a water bath and placed in an oven at 60 °C for 40, 60, 80, and 100 minutes. Then the product properties of the sausage were analyzed.

Analysis of Sausage Cooking Loss and Emulsification Ability. Refer to the method of Yun-Sang Choi [24]. Weigh 35 g sausage raw materials and chop them, put them in a 50ml centrifuge tube, and centrifuge (3000 rpm, 5 minutes) to remove air bubbles in the tube. Then heat it in a water bath (75 °C, 30 min), cool the heated sample at room temperature for 1 hour, weigh it after cooling, and record the mass. The cooking loss calculation formula was as follows (1). Pour the liquid lost during heating (invert the centrifuge tube for 40 minutes) into a glass dish and heat it at 105 °C for 16 hours. The weight lost by evaporation was water loss and the remaining mass after the bottom of the plate was dried was fat loss. The calculation formulas for water loss and fat loss were (2) and (3).

$$\text{Cooking Loss (\%)}=[W_0(\text{g})-W_1(\text{g})/W_0\ (\text{g})]\times 100. \quad (1)$$

$$\text{Moisture Loss (\%)}=(W_2-W_3)/W_0\times 100. \quad (2)$$

$$\text{Fat Loss (\%)}=W_3/W_0\times 100, \quad (3)$$

where W_0 – weight of raw meat batters, W_1 – weight of cooked meat batters, W_2 – weight of cooking liquid, W_3 – remaining weight after heating.

Color difference analysis was to use a colorimeter and O/D test head to determine the brightness value (L^*), redness value (a^*) and yellowness value (b^*). The sausages stored at 4 °C were measured directly after equilibrating at room temperature for 1 hour.

Weigh 5 g of sausage samples and crush them, put them into a 50 mL beaker, add 20 mL of distilled water, magnetically stir for 5 minutes, and stand still for 30 minutes [25]. Use a pH meter to measure the intermediate liquid. After the reading is stable, read directly and record the data. All determinations were performed in triplicate.

The sausages stored at 4 °C were placed at room temperature to equilibrate the temperature, the samples were cut into cylinders of 40×20 mm (height×diameter), and the texture was measured. Sausages are punctured to measure sausages using texture planer analysis (TPA). Select P/5 as the probe model. Let's set the measured parameters, 5 mm/s before the test rate, 1 mm/s test rate, 1 mm/s after the test rate, 50 %. The compression ratio, 5 g trigger force. The measurement indicators include six parameters of hardness, elasticity, cohesiveness, chewiness, adhesiveness and recovery.

Low-field nuclear magnetic resonance (LF-NMR) technology was used to determine the dynamic distribution of moisture inside sausages. The sausage was cut into 0.8 cm wide and 3 cm high and placed in a nuclear magnetic test tube (the diameter of the test tube was 1.5 cm, the height was 20 cm), the magnetic field strength was 0.47 T, and the proton resonance frequency was 20 MHz [26]. The Carr-Purcell-Meiboom-Gill (CPMG) program was used to determine the sample relaxation time (T_2). When each sample was measured, the program automatically scans 100 times, and each scan time was 100s. The T_2 was inverted through CONTIN software to reflect the corresponding relaxation times (T_{2b}, T_{21}, and T_{22}) and amplitudes (A_{2b}, A_{21}, and A_{22}) [27].

Invite 10 food graduate students with sensory evaluation experience to form an evaluation team. Use 0 to 10 points to indicate the degree of like. Mainly evaluate the color, hardness, flavor, viscosity and overall acceptability of braking time of bran-duck-pork sausage.

Data analysis Excel and DPS V_8.5 were used for data analysis, Duncan's multiple comparison method was used to analyze the significance of differences, and Origin 2019*b* was used for drawing, and each group of data used 3 replicates.

5. Results of studying the effect of baking time on the quality of bran – duck – pig sausage

5. 1. Research results on sausage cooking loss, emulsion stability, color, moisture content, pH

The emulsification stability of sausage is indirectly evaluated by water loss and fat loss. The effect of baking time on Cooking loss and Emulsification Ability of sausages was shown in Table 1.

Table 1

The effect of baking time on cooking loss and emulsification stability of bran-duck- pig sausages

Treatment	Cooking loss, %	Moisture loss, %	Fat loss, %
40 min	2.38±0.03*a*	1.81±0.14*a*	0.57±0.04*ab*
60 min	2.06±0.07*b*	1.43±0.04*b*	0.63±0.04*ab*
80 min	2.01±0.03*b*	1.47±0.10*b*	0.54±0.04*b*
100 min	1.99±0.05*b*	1.32±0.04*b*	0.65±0.06*a*

As the baking time increases, the cooking loss process decreases, and the baking time of 60–100 minutes in the experimental group was significantly lower than 40 minutes. The change trend of water loss and cooking loss was the same, and the difference in fat loss was not significant. The test results showed that the longer the baking time, the smaller the cooking loss and the better the emulsification stability. Considering the processing time and energy factors, the 60 min treatment group was the best.

Color is an important indicator of sausages. The effect of baking time on the color of sausages was shown in Table 2.

Table 2

The effect of baking time on the color of bran-duck-pig sausages

Treatment	*L*	*a*	*b*
40 min	56.29±0.36*a*	16.72±0.18*a*	18.65±0.42*b*
60 min	53.09±0.10*b*	17.45±1.89*a*	20.11±1.65*a*
80 min	54.06±0.75*b*	16.85±0.36*a*	20.46±0.79*a*
100 min	53.72±3.41*b*	16.97±0.19*a*	19.09±1.51*ab*

The results showed that with the increase of baking time, the brightness of sausages had a decreasing trend, and baking 60 min was significantly lower than 40 min. The red a value had increased slightly, but the difference was not significant. Although there was a difference in the yellow value *b*, the numerical difference was not large. Therefore, baking time could reduce the brightness of the bran-duck-pig sausage, and the red and yellow changes were not obvious.

The moisture content of the sausage is directly affected by the baking time. The moisture content results were shown in Fig. 1.

The moisture content of the sausage with the baking time of 40min is 62.49 %, and the moisture content of 60, 80, 100 min are 57.37 %, 60.07 %, 42.43 %, respectively, showing a downward trend. The moisture content of the 80 min treatment group should be lower than 60 min in theory, which may be caused by Caused by test errors. It was better to choose a baking time of 60 min.

The pH changes of bran chicken sausages at different baking times were shown in Fig. 2.

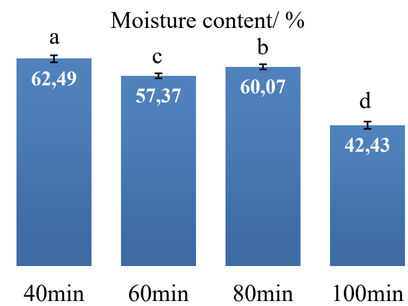


Fig. 1.The effect of baking time on moisture content results

Note: a, b, c and d represent the difference significance (0.05) results of multiple comparisons, indicating significant differences between groups

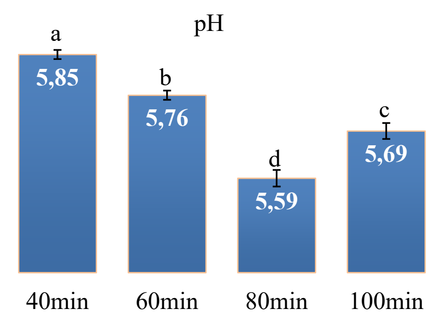


Fig. 2.The effect of baking time on pH results

Note: a, b, c and d represent the difference significance (0.05) results of multiple comparisons, indicating significant differences between groups

The pH of sausages ranged from 5.59 to 5.85, and the pH of sausages tended to decrease with increasing roasting time. The differences between each treatment group were significant. When the baking time was 80 min, the pH value of sausage was the lowest.

5. 2. Research results on texture properties of sausage

People like the elasticity and firmness of sausages. The effect of baking time on the texture characteristics of bran-duck-pork sausages was shown in Table 3. The research results showed that the values were increasing after the baking time reached 60 min, but the values were somewhat reduced when the baking time reached 80 min, and the values began to increase again after 100 min. In addition to the hardness, the values were also viscous and chewy. The properties, elasticity, cohesion and recovery all reached the maximum, followed by 60 min. There was no significant difference in hardness between 40 min and 60 min baking. There was no significant difference in cohesiveness between baking 60 min and 80 min. The viscosity and resilience of the two groups were similar when baking 60 min and 100 min.

On the whole, the sample has the best quality and taste when the baking time was 100 min. Because the effect of roasting treatment was mainly to improve the texture and chewiness of the meat, its elasticity and chewiness were greatly improved after 100 min of roasting.

Table 3

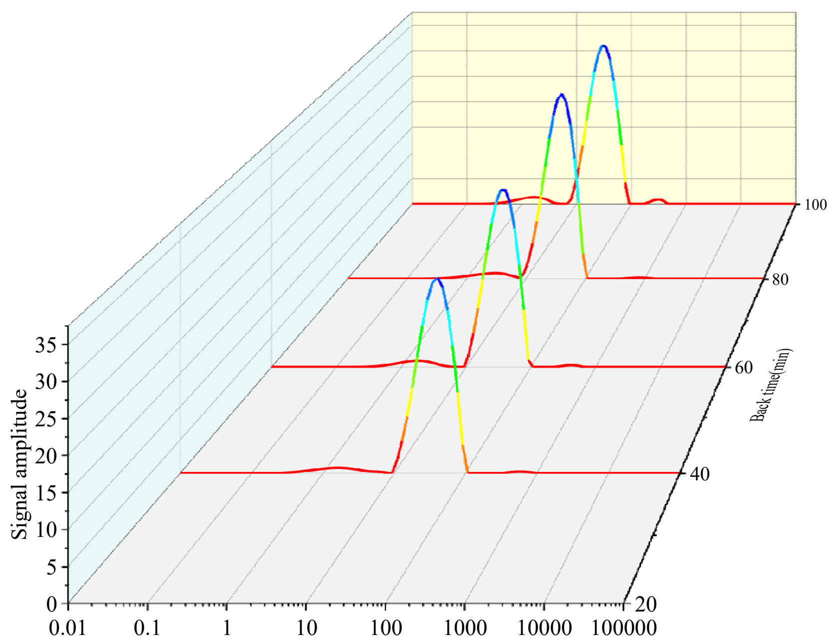
The effect of baking time on the texture properties of bran-duck-pig sausages

Treatment	Hardness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
40 min	101.4±11.6*b*	0.5±0.02*a*	0.31±0.01*a*	31.55±4.91*a*	15.81±2.81*a*	0.07±0.01*a*
60 min	134.4±30.8*a*	0.68±0.08*a*	0.38±0.07*a*	52.32±20.24*a*	34.54±10.05*a*	0.09±0.03*a*
80 min	81.3±1.16*b*	0.57±0.07*a*	0.38±0.08*a*	31.06±6.73*a*	18.04±6.14*a*	0.09±0.03*a*
100 min	92.7±9.09*b*	0.74±0.26*a*	0.43±0.11*a*	40.50±14.69*a*	32.36±22.26*a*	0.11±0.04*a*

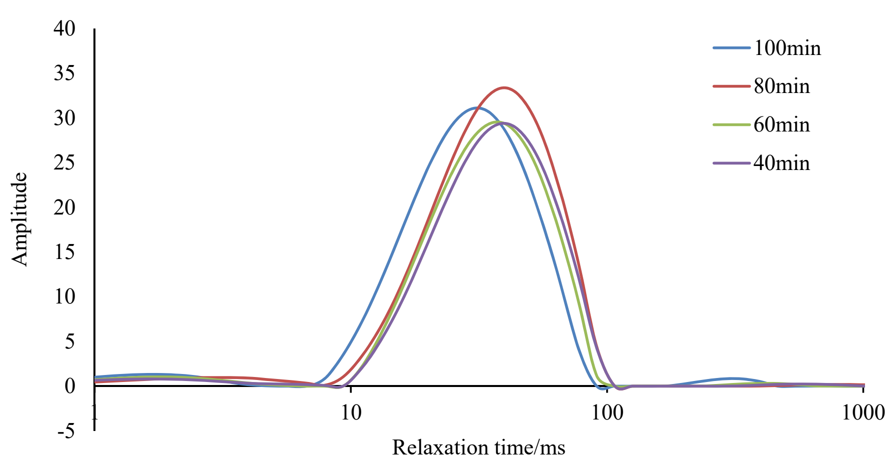
5. 3. Research results on distribution of water of sausage

Using low-field nuclear magnetic resonance technology to measure the distribution of water in sausages can explain the state of water and protein binding and reflect the water holding capacity of protein gels. The fitted T_2 distribution presents three peaks according to the relaxation time. According to the different degrees of free movement of water molecules, they indicate bound water (T_{2b}), non-flowing water (T_{21}) and free water (T_{22}) from left to right. In this study, the relaxation times (T_2) corresponding to hydrated water, fixed water, and free water were 0.1–9.3 ms, 10–91 ms, and 175–900 ms, respectively.

It can be seen from the *Z* coordinate axis in following Fig. 3, *a* that the 80 and 100 min treatment groups shifted to the left when the relaxation time was 10 ms, indicating that the relaxation time became smaller and the bound water distribution was relatively large, indicating that the more the baking time increases, the closer the protein and water were combined, the more the bound water content increases, and the free water changes to water that was not easy to flow.



a



b

Fig. 3.Effects of Baking Time on Moisture Distribution of Sausages:
a – 3D-waveform of transverse relaxation time T_2; *b* –2D composite plot of transverse relaxation time T_2

Fig. 3, *b* above showed clearly that the baking time of 80 and 100 min was shifted to the left. Between 10 and 100 ms, the 80 min treatment group had the largest peak area, followed by the 100, 60 and 40 min treatment groups with the smallest peak area and little difference. This indicated that the semi-bound water content in the samples in the 80 min treatment group was the highest and the distribution was the widest.

5. 4. Research results on sensory evaluation of sausage

The roasting process can disperse the fat in the sausage minced meat, promote the ripening of the protein, and make the sausage meat better. Sensory evaluation directly reflects the acceptance of the product. The results in Table 4 showed that as the baking time increases, the sensory evaluation score was higher, and the highest score was 6.15 in 100 minutes. Besides, in this study, the flavor sensory score of the 40 min treatment group was significantly lower than that of the other treatment groups, and the viscosity and overall acceptance of the casing in the 100 min treatment group were significantly higher than those of the other treatment groups. The possible reason was that the meat quality gives the sausage a special flavor and reduces the excess moisture content during the baking process.

Table 4

The effect of baking time on the sensory evaluation of bran-duck-pig sausages

Treatment	Color	Flavor	Texture	Viscosity	Acceptability
40 min	5.7±0.67*a*	4.8±0.79*b*	5.8±0.79*a*	5.6±0.69*b*	5.47±0.46*b*
60 min	5.9±0.74*a*	5.6±0.70*a*	5.7±0.67*a*	5.8±0.78*b*	5.75±0.13*ab*
80 min	5.8±0.63*a*	5.7±0.67*a*	5.9±0.74*a*	6.1±0.74*b*	5.87±0.17*ab*
100 min	5.7±0.63*a*	6.0±0.82*a*	5.9±0.87*a*	6.9±0.87*a*	6.15±0.51*a*

In addition, the baking of sausages could increase the color and tissue state of the casing. Although the color evaluation scores were not different, the eyes could see that the long-term baking gives the sausage meat a dark color. Based on the above research results on sausage quality, the optimal baking time for sausage was determined to be 6080 min in this study.

6. Discussion of results of studying the effect of baking time on the quality of bran-duck-pig sausage

The cooking loss value is an important indicator for evaluating the quality of meat products, which reflects the loss of juice during the heating process of meat products. Make the sausage more elastic and juicy, and strengthen the sausage taste. Water retention reflects the ability of the meat gel to bind free water molecules inside. In addition, wheat bran contains a lot of dietary fiber and polysaccharides. Polysaccharides are hydrophilic and can combine with water during the heating process, thereby causing changes in the interaction force between protein molecules and causing the occurrence of protein-protein interactions. The complexation reaction forms a denser three-dimensional network structure, which further binds water molecules [28], thereby reducing the cooking loss of sausage and improving the emulsion stability [29, 30].The results of this study showed that increasing the baking time reduced cooking losses consistent with previous results.

pH is one of the important factors reflecting the quality of meat products, and has an important effect on the taste, color and stability of meat products. High pH adversely affects the activity of lipids and proteolytic enzymes in meat, and ultimately affects the shelf life and flavor of meat products [31]. The results in Fig. 2 showed that the pH value decreases significantly with the baking time. The trend was favorable for the formation of sausage quality, and the pH was the lowest at 80min.Unfortunately, the pH results were not regular with bake time.

The results of the samples' obtained texture properties (Table.3) shown that roasting improves sausage firmness, elasticity, cohesion, stickiness, chewiness, and recovery. The results of this study showed that the hardness of sausages baked for 60 min increased by 32.5 %, and the difference was significant (P>0.05). All other results varied but were not significantly different. The addition of wheat bran improved the nutritional profile of the sausage, but decreased the sausage firmness, which is a good result for 60 minutes of baking to improve the firmness and other textural properties of the sausage. Some researchers have improved the best chewing sensation of sausages by adding edible gums, such as gelatin, xanthan gum, etc., to improve the loss of firmness caused by the addition of cellulose. The baking process is easy to implement and enhances the flavor and color of the cooked sausage compared to using food glue.

The moisture content can only represent the moisture content of the sausage, but it is unknown how much the moisture content distribution of the three states increases or decreases. The low-field (0.5T) NMR technique can further indicate the distribution state of the three kinds of water in the sausage [32]. The NMR signal of sausage is composed of three wave peaks formed by the inversion of the transverse relaxation time T_2. According to these three peaks, it is divided into three water states, which are denoted from left to right as hydrated water (T_{2b}) and immobilized water (T_{21}) and free water (T_{22}) [33]. In this study, the relaxation times (T_2) corresponding to hydrated water, fixed water, and free water were 0.1–9.3 ms, 1091 ms, and 175–900 ms, respectively. The results of this study are shown in Fig. 3. The T_2 relaxation time shifts to the left with the increase of baking time, indicating that the free water decreases and the semi-bound water and bound water increase relatively, which is consistent with the law that the baking process reduces moisture. When the three-dimensional diagrams are combined together, it can be clearly found that the 80min treatment group has the largest semi-bound water peak area and the largest semi-bound water content, followed by the 100, 60 and 40 min treatment groups with no significant difference. There is still a little doubt, the transverse relaxation time of the 100 min treatment group has a more obvious front between 100 ms and 1000 ms, which is different from common sense and needs further research.

Roasting can accelerate the process of Maillard reaction and caramelization reaction, improve the color of sausage and increase the aroma components [34]. The sensory panelists did not differ significantly between 60 and 100 min in the overall sausage acceptability (although the 100 min panel received the highest score). Studies have reported that the higher the baking temperature and the longer the baking time, the higher the sensory score of the sausage [20], this view was consistent with the results of this study. In addition, with the obvious change in the color of the sausage, the lightness value (L) of the color decreased significantly compared with 40 min for 60~100 min. Based on the color score, flavor and texture score in Table 4, it is reasonable to bake the sausage for 60–80 min.

7. Conclusions

1. The research results showed that the cooking loss of sausage juice of the 60–80 min treatment group was significantly lower than that of the 40 min treatment group; the 60 min treatment group had the smallest lightness value L, the highest redness value a, and the best color; the 40 min treatment group had the highest water content, and the 80 min treatment group had the highest water content. The pH value of the remaining 80 min treatment groups was also the lowest. The results of this study showed that the hardness of sausages baked for 60 min increased by 32.5 %, and the difference was significant (P>0.05).

2. In terms of texture properties, the results of this study showed that the hardness of sausages baked for 60 min increased by 32.5 %, and the difference was significant (P>0.05). All other results varied but were not significantly different.

3. In this study, the relaxation times (T_2) corresponding to hydrated water, fixed water, and free water were 0.1–9.3 ms, 10–91 ms, and 175–900 ms, respectively. When the baking time is 80 min, the peak area corresponding to the T_2 relaxation of the sausage was the largest, and the semi-bound water content is the largest.

4. Baking time affects the cooking loss, color, pH, texture, moisture distribution and sensory evaluation results of emulsified sausages. Therefore, the baking process is very important. Based on the above research results of sausage quality, the optimal baking time of sausage in this study was 6080 min. This research provides technical support for sausage baking process.

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