Effect of NaCl on volatile flavor compounds and water distribution in pig skin jelly

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Abstract: The dynamic changes of key volatile compounds and water distribution in the pig skin jelly with different NaCl addition (0.0%, 0.5%, 1.0%, 2.0%, and 4.0%) were identified and analyzed. A total of 28 volatile compounds were identified in all samples of pig skin jelly. Compared with the sample without NaCl addition, aldehydes, alcohols and ketones were significantly increased in the pig skin jelly with NaCl addition. In addition, 12 key volatile flavor compounds, including hexanal, nonanal, octanal, (E,E)-2,4-decadienal, (E,Z)-2,6-nonadienal, (E)-2-nonenal, (E)-2-heptenal, (E)-2-octenal, 1-hexanol, 2-ethyl-1-hexanol, 1-octen-3-ol and 2,3-octanone were further identified. With the increase of NaCl concentration, the free water located in the intercellular space was transformed into immobilized water entrapped in the myofibrillar network, increasing the water-holding capacity of pig skin jelly. Correlation analysis showed that $T_{23}$ had strong negative correlations with (E)-2-nonenal and 1-hexanol, $T_{23}$ had strong negative correlation with (E,E)-2,4-decadienal, and positive with (E,Z)-2,6-nonadienal and (E)-2-heptenal, and $T_{23}$ had strong negative correlations with (E,Z)-2,6-nonadienal and (E)-2-heptenal. In conclusion, this study provides a reference for the utilization of pig by-product and salt reduction of Chinese meat products.

Keywords: pig skin jelly; volatile flavor compounds; water distribution; NaCl addition; correlation analysis


1 Introduction

The total annual output of pork all around the world was over 100 million tons in 2020[1]. At the same time, China was the leading producer of pork and contributed approximately 40% of the total production[2]. China was also the country with the highest consumption of pork in the world in 2020, accounting for 44.3% of the world's pork consumption[3]. However, as one of the byproducts, pig skin is not accepted by many people because pork with pig skin was too greasy and difficult to chew. In order to solve this problem, pig skin was processed in another way to produce food that met the taste of consumers. Pig skin jelly, also known as “pi-dong” in Chinese, is a kind of food with high protein content, special flavor, and palatable chewiness cooked from pig skin. Pig skin jelly is sold in all major markets. In the traditional Chinese New Year, pig skin jelly is an indispensable dish for entertaining relatives and friends, especially in some northern provinces of China.

The meat quality characteristics generally influence the consumer’s purchase intention, and meat products with abundant taste and flavor are always more popular[1]. The addition of NaCl can improve the texture and flavor of meat products, as well as facilitate processing[1]. NaCl addition in meat products may also have positive effects on water/fat-holding capacity, decreasing cooking loss and improving taste[1]. With the decrease in NaCl content, the swelling and solubility of myofibrillar proteins, and the quality of meat gel decreased[1].

However, excess NaCl consumption in the human diet, on the other hand, have been linked to hypertension and cardiovascular disease[4]. In some western countries, 16%–25% of NaCl intake in the daily diet comes from meat and meat products[5]. The World Health Organization (WHO) recommends a maximum amount of salt intake of 5 g/d, whereas the ordinary adult consumes 9–12 g/d[6]. For this reason, WHO had formulated a strategy of reducing salt by 30% by 2025[7]. In addition, the prevalence of cardiovascular diseases caused by a high-salt diet has increased significantly among Chinese residents according to the Health China Action (2019–2030) and the Scientific Research Report on the Dietary Guidelines for Chinese Residents (2021)[8]. In order to reconcile the contradictory studies, it is necessary to investigate the effects of different NaCl contents on the perception of flavor and taste characteristics of meat-related products and provide guidance for reducing NaCl intake, thus enhancing their health benefits.

Therefore, the study aimed to investigate the effect of NaCl addition on volatile flavor compounds and water distribution in pig skin jelly. The study may provide guidance for the manufacture of nutritious and healthy meat products and the research and development of low-salt pig by-product food.

2 Materials and methods

2.1 Reagents and chemicals

The raw pig skin was purchased from a local market in Yinchuan (Ningsia, China). Sigma-Aldrich (Shanghai, China)
provided the following chemicals: 1,2-dichlorobenzene (internal standard, 99.78%), n-alkanes (C_{22}–C_{34} ≥ 97.0%), hexanal (≥ 95.0%), (E,Z)-2,6-nonenal (≥ 96.0%), 1-hexanol (≥ 99.5%), (E)-2-nonenal (≥ 95.0%), 2-ethyl-1-hexanol (≥ 99.0%), octanal (≥ 99.0%), (E)-2-octenal (≥ 97.0%), and nonanal (≥ 99.5%). 2,3-Octanone (≥ 97.0%) was purchased from Macklin Biochemical Co., Ltd. (Shanghai, China). (E,E)-2,4-Decadienal (≥ 94.0%), (E)-2-heptenal (≥ 97.0%), and 1-octen-3-ol (≥ 98.0%) were purchased from TCI Development Co., Ltd. (Shanghai, China).

2.2 Sample preparation
The hair of the pig skin was cleaned and removed. Firstly, the pig skin was put into boiling water and boiled for 2 min. The grease on the pig skin surface was scraped off thoroughly after cooling. Secondly, the pig skin was cut into small pieces (0.5 cm × 2.0 cm). Pig skin samples (150.00 ± 0.01 g) were placed into water (600 g) and boiled for 100 min. Then NaCl with the mass ratio (NaCl/pig skin, m/m) of 0.0%, 0.5%, 1.0%, 2.0%, and 4.0% was added, respectively. Finally, the liquid pig skin jelly was cooled at room temperature ((20 ± 5) °C) under natural conditions. The samples were analyzed after cooling for 12 h.

2.3 Analysis of aroma compounds

2.3.1 Gas chromatography-mass spectrometry (GC-MS) analysis
The volatile compounds in pig skin jelly were separated and identified by GC-MS (GC-MS 2010 Plus, Shimadzu, Japan) equipped with a DB-WAX capillary column (30 m × 0.25 mm, 0.25 μm, Agilent Technologies, Inc., USA). Briefly, the sample (12.00 ± 0.01 g) was put in a 15 mL headspace bottle. Immediately after, 4 μL of internal standard (1,2-dichlorobenzene, 6.42 μg/mL in methanol) was injected into the sample quickly and the headspace bottle was sealed. The headspace bottle was immersed in the water bath at 55 °C for 20 min. The volatile compounds in the sample of pig skin jelly were extracted by 50/30 μm DVB/CAR/PDMS coating fiber (Supelco, Inc., Bellefonte, PA, USA) for 30 min. After the extraction, the solid-phase microextraction (SPME) fiber was immediately inserted into a GC injection port at 250 °C for 3 min for desorption. The GC conditions and the temperature program were according to Wang et al.[11].

2.3.2 Qualitative and quantitative analysis of volatile compounds and screening of key volatile compounds
The NIST 14 database, retention indices (RI) and authentic standards (S) were used to identify the volatile compounds in the samples with different NaCl contents. The formula for the calculation of RI was according to Tian et al.[13]. 1,2-Dichlorobenzene was used as an internal standard for the quantitative analysis of all volatile compounds in the samples. The odor activity values (OAVs) were calculated by dividing the concentration by its odor threshold (OT). In general, the compounds in pig skin jelly with OAV ≥ 1 were regarded as key volatile compounds[13-14]. The OAV contribution rates were determined by dividing the OAV of each key aroma compound with OAV of all key aroma compounds.

2.4 Analysis of water distribution
The water distribution in pig skin jelly was analyzed using the method described by Wang et al.[15]. The samples (2 cm × 1 cm × 1 cm) were placed in an NMI20-NMR analyzer (Niumag Co., Ltd., Shanghai, China) to analyse the T$_2$ transverse relaxation. The T$_2$ was measured through the Carr-Purcell-Meiboom-Gill (CPMG) sequence and relevant parameters described by Wang et al.[15].

2.5 Sensory evaluation
A total of 10 graduate students (5 females and 5 males, aged 22–25 years), Ningxia University participated in evaluating the color, flavor, taste (saltiness), texture (comprehensive hardness, springiness, and chewiness), and overall acceptability of pig skin jelly[15-16]. The participants received approximately 30 d of training before the evaluation. The preference of participants was also measured using a nine-point scale. To avoid the interaction between samples, the participants were asked to gargle with purified water and take a rest of 1 min after evaluating a sample. The sensory evaluation criteria were shown in Table 1.

<table>
<thead>
<tr>
<th>Sensory index</th>
<th>General description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Not too bright light brown</td>
<td>4–6</td>
</tr>
<tr>
<td></td>
<td>Matt dark yellow</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>No pungent odor, very strong pleasant odor</td>
<td>7–9</td>
</tr>
<tr>
<td>Flavor</td>
<td>No pungent odor, a little pleasant odor</td>
<td>4–6</td>
</tr>
<tr>
<td></td>
<td>No pungent odor, no pleasant odor</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Normal salty</td>
<td>7–9</td>
</tr>
<tr>
<td>Taste</td>
<td>Little salty</td>
<td>4–6</td>
</tr>
<tr>
<td></td>
<td>Very salty</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Flexible, chewy</td>
<td>7–9</td>
</tr>
<tr>
<td>Texture</td>
<td>Fragile, unformed</td>
<td>4–6</td>
</tr>
<tr>
<td></td>
<td>Hard, toothing</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>The best color, flavor, taste and texture</td>
<td>7–9</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>Good color, flavor, taste and texture</td>
<td>4–6</td>
</tr>
<tr>
<td></td>
<td>The worst color, flavor, taste and texture</td>
<td>1–3</td>
</tr>
</tbody>
</table>

2.6 Statistical analysis
All measurements were repeated in triplicate. Results were shown as means ± standard deviation. Data were analyzed by ANOVA, followed by Duncan’s multiple range test using SPSS 19.0 software (IBM Corporation, USA), with the significance at the level of P < 0.05. Some figures were plotted by Origin 18C, and other figures were plotted using http://www.bioinformatics.com.cn.

3 Results

3.1 Changes of volatile compounds in pig skin jelly
The flavor was a significant quality attribute of food and affected the consumption tendency of consumers[19]. The odor-active organic compounds in meat and meat products were mostly composed of aldehydes, ketones, alcohols, esters, acids, and heterocyclic compounds. In this study, volatile organic components of pig skin jelly with different NaCl contents were extracted and evaluated utilizing GC-MS. A total of 28 volatile compounds were identified and selected in all
samples and the samples were separated by principal components analysis (PCA) of GC-MS data (Figures 1 and 2). These compounds represented 5 chemical classes, including aldehydes (13), alcohols (8), ketones (5), acids (1), and other compounds (1). By analyzing the odor data of the samples with different NaCl contents, it can be found that the type and content of the volatile compounds in the samples showed a certain change with the increase in NaCl concentration. Compared with the sample without NaCl addition, the contents of aldehydes, alcohols, and ketones in the pig skin jelly with NaCl addition mostly increased significantly ($P < 0.05$) (Table 2). The total content of all volatile compounds was increased with NaCl addition from 0.0% to 1.0% and then significantly decreased. This result was similar to the total content of alcohol compounds, whereas the total content of aldehydes and ketones did not change significantly. This may result from the following two processes: 1) During the brewing process of skin jelly, NaCl acts as an electrolyte to promote the volatilization of flavor substances, resulting in a decrease in the content of flavor substances retained in the skin jelly; 2) The presence of NaCl in the extraction process of flavor substances in skin jelly can also affect the volatilization of residual volatile flavor substances in skin jelly. All the compounds, except (E,E)-2,4-heptadienal, (E)-2-decenal, 1-nonanal, (E)-2-non-en-1-ol, 6-methyl-3,5-heptadiene-2-one, acetaldehyde, acetic acid, and undecane, were detected in all samples. Hexanal (22.80–86.99 μg/kg), nonanal (13.53–21.92 μg/kg), 1-hexanol (7.32–26.78 μg/kg), 2-ethyl-1-hexanol (40.22–184.82 μg/kg), 1-octen-3-ol (7.28–22.98 μg/kg), 1-pentanol (3.06–13.90 μg/kg) and 2,3-octanedione (23.63–60.89 μg/kg) were the primary volatile compounds with concentrations >10 μg/kg and present in all samples.

Figure 1 PCA of pigskin jelly with different NaCl contents by GC-MS analysis.

Volatile compounds with OAV > 1 were considered key flavor substances and had a significant impact on the overall flavor of the sample[21]. Among 28 volatile compounds, 12 key volatile flavor compounds were further screened by calculating the ratio of concentration to odor threshold, including hexanal, nonanal, octanal, (E,E)-2,4-decalinal, (E,Z)-2,6-nonadienal, (E)-2-nonenal, (E)-2-heptenal, (E)-2-octenal, 1-hexanol, 2-ethyl-1-hexanol, 1-octen-3-ol, and 2,3-octanedione. Among them, (E,E)-2,4-decalinal had the largest OAV contribution rate, whether with NaCl addition or not in the samples. In addition, it was worth noting that the OAV contribution rates of 1-octen-3-ol and hexanal in the sample with NaCl addition were higher than without NaCl addition, but nonanal showed the opposite result.

Figure 2 (A) Clustering heatmap of the concentrations of volatile compounds in pig skin jelly with different NaCl contents; (B) Changes in OAV contribution rates of key aroma compounds (OAV > 1) in pig skin jelly with different NaCl contents.

3.2 Change of water distribution and mobility in pig skin jelly

The changes in water had a profound influence on essential quality attributes of meat and meat products, like juiciness, tenderness, firmness, and appearance[22–24]. Low-field nuclear magnetic resonance (LF-NMR) has been used to study the water mobility in numerous food products[25]. As shown in Figure 3 and Table 3, the relaxation spectra in pig skin jelly exhibited three types of water components. The minor and fastest $T_2$ peak at 0.01 and 10 ms could be attributed to the bound water. The $T_2$ peak between 10 and 100 ms represented immobilized water. The largest and lowest $T_2$ peak in the range of 100 and 1 000 ms could be attributed to the free water.

NaCl, an essential condiment in the processing of meat products, improved texture and decreased water activity[25]. The $T_2$ increased and the $T_2$ decreased with the increase in NaCl concentration.
Table 2  Total concentrations of different types of volatile compounds in pig skin jelly with different NaCl contents. (μg/kg)

<table>
<thead>
<tr>
<th>Type</th>
<th>NaCl content (%)</th>
<th>0.0</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldehydes</td>
<td></td>
<td>60.51 ± 12.55^a</td>
<td>137.63 ± 21.34^a</td>
<td>104.49 ± 13.00^a</td>
<td>135.99 ± 27.21^a</td>
<td>114.89 ± 8.09^a</td>
</tr>
<tr>
<td>Alcohols</td>
<td></td>
<td>62.48 ± 16.15^a</td>
<td>186.03 ± 41.85^b</td>
<td>252.88 ± 28.76^b</td>
<td>209.57 ± 35.71^b</td>
<td>99.82 ± 9.32^c</td>
</tr>
<tr>
<td>Ketones</td>
<td></td>
<td>36.00 ± 5.45^c</td>
<td>75.14 ± 14.57^d</td>
<td>48.85 ± 4.21^e</td>
<td>50.38 ± 11.12^f</td>
<td>68.60 ± 14.04^g</td>
</tr>
<tr>
<td>Acids</td>
<td></td>
<td>2.29 ± 1.30^h</td>
<td>1.80 ± 0.98^i</td>
<td>0.00 ± 0.00^j</td>
<td>2.12 ± 0.58^k</td>
<td>2.81 ± 0.10^l</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>1.25 ± 0.25^m</td>
<td>1.76 ± 0.81^n</td>
<td>0.67 ± 0.13^o</td>
<td>0.87 ± 0.45^p</td>
<td>0.00 ± 0.00^q</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>162.52 ± 32.03^r</td>
<td>402.35 ± 76.08^s</td>
<td>406.88 ± 25.26^t</td>
<td>398.93 ± 68.19^u</td>
<td>286.13 ± 17.97^v</td>
</tr>
</tbody>
</table>

Note: Different letters within the same row indicate significant differences (P < 0.05).

Table 3  T2 relaxation parameters of pig skin jelly with different NaCl contents.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>NaCl content (%)</th>
<th>0.0</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2 (ms)</td>
<td></td>
<td>26.88 ± 7.19^v</td>
<td>27.52 ± 3.27^w</td>
<td>30.50 ± 3.27^x</td>
<td>41.34 ± 4.95^y</td>
<td>31.03 ± 0.00^z</td>
</tr>
<tr>
<td>A21 (%)</td>
<td></td>
<td>0.06 ± 0.04^a</td>
<td>0.44 ± 0.07^b</td>
<td>0.74 ± 0.17^c</td>
<td>0.00 ± 0.00^d</td>
<td>0.03 ± 0.04^e</td>
</tr>
<tr>
<td>A22 (%)</td>
<td></td>
<td>1.62 ± 0.33^f</td>
<td>1.77 ± 0.05^g</td>
<td>1.77 ± 0.18^h</td>
<td>4.06 ± 0.05^i</td>
<td>3.87 ± 0.35^j</td>
</tr>
<tr>
<td>A23 (%)</td>
<td></td>
<td>98.32 ± 0.33^k</td>
<td>97.79 ± 0.12^l</td>
<td>97.49 ± 0.21^m</td>
<td>95.94 ± 0.05^n</td>
<td>96.10 ± 0.33^o</td>
</tr>
<tr>
<td>Total peak integral area</td>
<td></td>
<td>10 726.53 ± 281.10^p</td>
<td>8 777.45 ± 42.34^q</td>
<td>7 568.83 ± 53.43^r</td>
<td>6 663.10 ± 447.79^s</td>
<td>5 655.45 ± 55.56^t</td>
</tr>
</tbody>
</table>

Note: Different letters within the same row indicate significant differences (P < 0.05).

(Figure 3), but the change in T2 was not obvious. Additionally, the peak of T22 and T23 migrated from the right to the left. A21, A22 and A23 represented the areas of relaxation times T21, T22 and T23 respectively. As shown in Table 3, the A23 of pig skin jelly decreased from 98.32% (0.0% NaCl) to 96.10% (4.0% NaCl). At the same time, the A21 of pig skin jelly increased from 1.62% (0.0% NaCl) to 3.87% (4.0% NaCl). The A22 was not changed significantly, mainly because of its low proportion. The total peak integral area decreased significantly, indicating that the level of water in pig skin jelly decreased.

Figure 3 Distribution of T2 relaxation time of pig skin jelly with different NaCl contents.

3.3 Correlation analysis

Based on GC-MS and LF-NMR analysis, 12 key volatile components were selected to correlate T2 signals of pig skin jelly with different NaCl contents (Figure 4). The results showed that the T21 was negatively correlated with all the key volatile compounds, except (E)-2-octenal, 2,3-octanediene and (E,E)-2,4-decadienal. T22 was positively correlated with all the key volatile compounds, except 2,3-octanediene and (E,E)-2,4-decadienal. The total peak integral area, T22 and A23 signal were negatively correlated with all the key volatile compounds, except (E)-2-nonenal, octanal and (E,E)-2,4-decadienal. A23 was positively correlated with hexanal, 1-hexanol, 2-ethyl-1-hexanol, 1-octen-3-ol and 2,3-octanediene, and negatively correlated with (E,Z)-2,6-nonadienal, nonanal, octanal, (E,E)-2,4-decadienal, (E)-2-nonenal, (E)-2-heptenal and (E)-2-octenial. A22 was positively correlated with all the key volatile compounds, except octanal, (E,E)-2,4-decadienal, (E)-2-nonenal and 2-ethyl-1-hexanol.

Figure 4 Correlations among T2 relaxation parameters and key aroma compounds in pig skin jelly with different NaCl contents.

3.4 Sensory evaluation

Sensory evaluation was the direct indicator to measure consumer attitudes toward food[1]. As shown in Figure 5, the pig skin jelly...
with 1.0% NaCl gained high scores of flavor and taste. The pig skin jelly with different NaCl contents were no significantly different in color, while the pig skin jelly with 4.0% NaCl exhibited a high score of texture. Combined with taste, flavor, texture and color, the pig skin jelly with 1.0% NaCl had the highest overall acceptability score.

4 Discussion

4.1 Aldehydes and alcohols were affected by NaCl in the pig skin jelly

Aldehydes and alcohols were the main volatile flavor compounds in meat and meat products, especially some saturated or unsaturated aldehydes and alcohols with C₆-C₁₈ such as 1-hexan, hexanal, 1-heptanol, heptanal, (E,E)-2,4-heptadienal, 1-octan, 1-octen-3-ol, (E)-2-octenal, (E)-2-octen-1-ol, octanal, nonanal, 1-nonanal, (E,Z)-2,6-nonadienal, decanal and (E,E)-2,4-decadienal. These compounds were the products of lipid oxidation or degradation, and most of them were generally described as fatty, green, herbaceous, cereal-like, and sweet odor. Aldehydes and alcohols (21) were detected in the samples of pig skin jelly with different NaCl contents, of which 11 were identified as key volatile compounds, including hexanal, nonanal, octanal, (E,E)-2,4-decadienal, (E,Z)-2,6-nonadienal, (E)-2-nonenal, (E)-2-heptenal, (E)-2-octenal, 1-hexanol, 2-ethyl-1-hexanol and 1-octen-3-ol. The total concentration of aldehydes and alcohols in the sample of pig skin jelly accounted for more than 75% of the concentration of all compounds and contributed 96.27%–96.83% of the OAVs of key volatile compounds. The processing method could change the contents of the volatile compounds, but aldehydes and alcohols were still the main volatile compounds in meat. Compared to the pig skin jelly without NaCl addition, the concentration of most aldehydes and alcohols increased significantly. NaCl addition could enrich the flavor and aroma of meat products and reduce the perception of the bitter taste of some compounds. It was found that NaCl was the synergist for flavor in the dried bacon products and beef broth. NaCl could change the polarity of the protein surface, which was related to the adsorption of flavor compounds.

4.2 Aroma contribution and formation mechanism of key aroma compounds in pig skin jelly

A total of 332 odorants were identified in thermally cooked meat by GC-olfactometry. However, only a small number of volatile compounds made a significant contribution to the overall aroma of meat products. The compounds with a ratio of concentration to threshold greater than 1 (OAV > 1) were defined as key volatile substances. Among the volatile substances in pig skin jelly, a total of 12 substances were identified as key volatile substances, including hexanal, nonanal, octanal, (E,E)-2,4-decadienal, (E,Z)-2,6-nonadienal, (E)-2-nonenal, (E)-2-heptenal, (E)-2-octenal, 1-hexanol, 2-ethyl-1-hexanol, 1-octen-3-ol and 2,3-octanedione.

The formation of these volatile compounds was related to the degradation of lipids and each compound had its unique odor. Hexanal, a straight-chain aldehyde, was generated from the oxidation of linoleic acid and had a relatively high concentration and OAVs in pig skin jelly. Hexanal was responsible for the pleasant fatty aroma and grassy aroma in meat and meat products when they reached a high concentration and low concentration, respectively. In addition, the concentration of hexanal was found to be the highest in many meat and meat products, such as stewed mutton, roasted beef, roasted mutton, duck breast muscle, sauced-duck and emulsion sausage. As for other straight-chain aldehydes, the octanal presented meaty, grassy, and fresh aromas and nonanal mainly contributed to the grassy aroma notes. 1-Octen-3-ol, an unsaturated alcohol, was formed from the degradation of the secondary hydroperoxides of linoleic acid and catalolism of arachidonic acid and presented a strong mushroom aroma. Decanal and (E,E)-2,4-decadienal could be generated from the pyrolysis of y-linolenic acid. (E,Z)-2,6-Nonadienal presented green and cucumber odor and was generated from y-linolenic acid with 3 steps: 1) enzymatic peroxidation of y-linolenic acid; 2) acid-catalyzed degradation of y-hydroperoxide; 3) hydrolysis of ester and keto-enol tautomerism. (E)-2-Nonenal (fatty and paper odor), (E)-2-octenal (green and floral odor) and (E)-2-heptenal (fried and roasted meat odor) were produced by oleic acid. The retroaldolization of (E,E)-2,4-decadienal resulted in the formation of (E)-2-octenal. 2,3-Octanedione presented a creamy and fatty odor, was generated from the oxidation of linoleic acid, and was proposed as a biomarker of meat from grazing animals. Another formation pathway of 2,3-octanedione was the photo-oxidative degradation of furan fatty acids. 2-Ethyl-1-hexanol was a well-known compound associated with microbial metabolism and presented a minty odor.

4.3 Water migration of pig skin jelly with different NaCl contents

LF-NMR analysis of meat samples could provide information about water migration. It was generally considered that T2 reflected the bonding force between water and protein, giving their strong polar bonding. A high T2 value suggested a weak bonding force whereas a low T2 value suggested the opposite. It was found that T2 gradually decreased while the T2 increased with the addition of NaCl (Figure 3). Shorter relaxation time reflected a less mobile water portion, and longer relaxation time indicated that the water was restricted by the proteins. The increase in T2 indicated that water in pig skin jelly was more loosely bound with proteins. The percentages of peak areas (A₂, A₂, and A₃) corresponded to T2 relaxation time. No significant (P > 0.05) differences in A₂ of pig skin jelly with different NaCl contents were observed. The A₂ and
A22 in pig skin jelly, with the increase in NaCl content, were increased and decreased, respectively. The increase in A22 reflected the structural change because of the shrinkage and toughening of pig skin jelly as well as the loss of free water. The changes in A22 and A23 indicated that with the increase of NaCl content, the immobilized water was restricted to transform into free water during the cooking process. It also indicated that the existence of NaCl increased the physical and chemical interaction between water molecules and proteins. With increases in NaCl contents, water amounts in pig skin jelly corresponding to the T2 domain were redistributed and the water-holding capacity of pig skin jelly was increased23.

4.4 Correlation between T2 relaxation parameters and key aroma compounds

We have recently found the relationship between water migration and the change of non-volatile taste substances in cooked mutton, and confirmed the influence of moisture migration in meat on taste loss24. The transverse relaxation time of water and the free water ratio A22 were positively correlated with glutamic acid (Glu), adenosine monophosphate (AMP) and inosine monophosphate (IMP), and negatively correlated with threonine (Thr) and the bitter amino acids24. The proportion of immobilized water A23 was negatively correlated with Glu, AMP and IMP, and positively correlated with sweet amino acids (except Thr) and bitter amino acids24. In previous studies, few researchers have linked the water migration in meat products with the change of volatile flavor substances. Our research showed that there was a strong correlation between the water relaxation time, water proportion of each component and key aroma compounds in pig skin jelly under the influence of NaCl addition. The hypertonic environment formed by the increase of NaCl content may change the structure of collagen in pig skin jelly. It was reported that proteins had the ability to absorb volatile flavor substances25. Therefore, the change in protein structure may be an important reason for the change of volatile flavor in this study. At the same time, the water migration caused by a high salt level may also affect the content of some water-soluble volatile flavor substances.

5 Conclusion

The law of water migration and the changes occurring in volatile compounds of pig skin jelly with different NaCl contents were analysed in the study. A total of 28 volatile compounds were identified in all samples of pig skin jelly and 12 key volatile flavor compounds were further screened based on OAV. In pig skin jelly, the addition of NaCl promoted the formation of flavor substances. Compared with the sample without NaCl addition, aldehydes, alcohols and ketones were significantly increased in the pig skin jelly with NaCl addition. In addition, with the increase of NaCl concentration, the T23 and A23 decreased, while T22 and A22 increased. The free water located in the intercellular space was transformed into immobilized water entrapped in the myofibrillar network, increasing the water-holding capacity of pig skin jelly. Our next research will further understand the mechanisms by which water, NaCl, fatty acids and free amino acids regulate the formation of key volatile compounds in pig skin jelly at the chemical and molecular level.

Conflict of interest

The authors declare that they do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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