Evaluation of effects of ultrasound-assisted saucing on the quality of chicken gizzards

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ABSTRACT

The purpose of this study was to evaluate the effects of ultrasound-assisted saucing on the quality of chicken gizzards. The results showed that with the prolonging of the saucing time, the yield, water holding capacity (WHC), lightness (L*), redness (a*) and springiness of chicken gizzards significantly decreased, while the shear force, hardness and chewiness significantly increased (P < 0.05). When the saucing time was the same, the yield, WHC, springiness and tenderness of the ultrasound group were significantly higher than those of the non-ultrasound group (P < 0.05). In particular, when the saucing time was 30 min, the yield, WHC and springiness of the ultrasound group increased by 2.13%, 0.97% and 10.53%, and the shear force decreased by 21.22% compared with those of the non-ultrasound group, respectively. Besides, ultrasound pretreatment increased the content of aromatic compounds, short-chain alkanes, alcohols, aldehydes and ketones, and the principal component analysis displayed that C-50 (saucing for 50 min without ultrasound pretreatment) and U-30 (saucing for 30 min with ultrasound pretreatment) were similar in flavor. Therefore, ultrasound pretreatment is a potential way to improve the quality of saucing chicken gizzards and shorten the processing time.

1. Introduction

Chicken gizzard, also known as muscular stomach, is rich in nutrients, including about 20% protein, 4% carbohydrates and 2.8% fat [1]. In addition, it also contains a variety of trace elements, such as sodium, phosphorus, potassium, iron and so on. According to the “Compendium of Materia Medica”, chicken gizzards have the effects of eliminating food accumulation, antinausea and defecation, and people can enjoy the deliciousness of chicken gizzards while enhancing their health [2]. However, chicken gizzards, which are the digestive organ of chicken, are mainly responsible for grinding cereals and grits [3]. Klont, Brocks, and Eikelenboom [4] noted that the greater the exercise load, the greater the muscle toughness. As a result, chicken gizzards are tough and unchewable, which is not accepted by many people. Meanwhile, chicken gizzards are often discarded as a by-product, which causes waste of resources and environmental pollution. Therefore, to increase the value of the by-products of poultry meat and reduce the waste of resources, chicken gizzards can usually be consumed after cooking [5].

Saucing is one of the most common and typical cooking methods for chicken gizzards in China [6], which can improve the texture of chicken gizzards that are difficult to chew, give them a rich fragrance and remove the odor of chicken gizzards. However, the traditional way of saucing has the problem that the soup is difficult to penetrate due to the dense muscle texture of chicken gizzards [6]. At present, it is possible to promote the penetration of spices and seasonings by prolonging the saucing time [7]. However, prolonged saucing not only wastes energy but also reduces the yield of production [6]. Therefore, proper tender treatment of chicken gizzards in the early stage of saucing can improve the tenderness of chicken gizzards and save time, thus improving the product quality. At present, the tenderization methods of meat products include the enzymatic method, salt method, ultra-high pressure, ultrasound and so on [8]. However, ultrasound, as an emerging physical tenderization technology, has been widely used in the tenderization of meat and meat products for its efficient, safe and green advantages [9,10].

Ultrasound will produce cavitation effects when it propagates in a liquid medium. The cavitation effect is the main reason for physical and chemical changes in muscles [11]. Our previous study investigated that micro-jet and micro-turbulence generated by ultrasound cavitation could destroy the integrity of muscle fiber and connective tissue of chicken gizzards, leading to the decrease in the cross-linking degree of pyridine in collagen, thus improving the tenderness of chicken gizzards.
Therefore, this study investigated the effects of ultrasound-assisted saucing on the quality of chicken gizzards by measuring the yield, water holding capacity (WHC), moisture distribution, color, shear force, texture and flavor properties, which would provide theoretical reference and technical support for improving the quality of saucing products.

2. Materials and methods

2.1. Sample preparation

The chicken gizzards (12 h after being slaughtered, about 2.0 kg per Arbor Acres chicken raised for 50 days and 30 g per chicken gizzards) about 3.5 kg were purchased from Haoyouduo market (Harbin, China) and immediately shipped back to the lab with an ice bag (1 ~ 4 °C). After being removed the yellow skin and fat on the chicken gizzards’ surface, chicken gizzards were rinsed with water and put in a 4 °C refrigerator. The washed chicken gizzards were divided into two groups, one group was not treated with ultrasound (placed at 4 °C) and the other was treated with ultrasound (500 W, 30 min, 30 kHz, ultrasound for 3 s, intermittent 3 s, 4 °C).

2.2. Preparation of saucing chicken gizzards

After weighing, each group of chicken gizzards was pickled in brine (10 g of salt, 5 mg of sodium nitrite per 100 g of chicken gizzards, chicken gizzards: water = 1:2 (w/v)) for 30 min at 4 °C, stirring 3 ~ 4 times. The pickled chicken gizzards were put in the water at 80 ~ 90 °C for 4 ~ 5 min and then cleaned with water. This treatment was to force the bleeding water, remove the smell of blood and avoid the floating foam during the saucing process. When the brine was boiled, the chicken gizzards were soaked in brine for saucing. The brine was prepared by mixing 70 g of soybean sauce, 50 g of white wine, 20 g of salt, 4 g of monosodium glutamate, 10 g of ginger, 20 g of sugar, 40 g of five-spice powder, and 4 L of water per kilogram of chicken gizzards. After different saucing time (20, 30, 40, 50 min), the following indexes were determined.

2.3. Yield

The determination of yield was based on the method of Wang et al. [14] with a slight modification. The surface of the chicken gizzards before the saucing was dried with filter paper and weighed as \( W_1 \) (g). The brine on the surface of samples was removed after cooling and weighed again as \( W_2 \) (g). The formula was as follows:

\[
Yield(\%) = \frac{W_2}{W_1} \times 100
\]

2.4. Water holding capacity

The WHC of saucing chicken gizzards was as stated by Du et al. [15] with a slight modification. Single sample mass: 4 g, centrifugal tube specifications: 10 mL, centrifugal force: 6,500 × g, centrifugal time: 10 min, temperature: 4 °C. The samples before and after centrifugation were weighed and denoted as \( W_3 \) (g) and \( W_4 \) (g). The formula was as follows:

\[
\text{Water holding capacity}(\%) = \frac{W_4 - W_3}{W_1} \times 100
\]

2.5. Moisture distribution

The moisture distribution of saucing chicken gizzards was measured by a Minispec mq 20 Low field-nuclear magnetic resonance (LF-NMR) analyzer (Bruker Optik GmbH, Ettlingen, Germany) as described by Du et al. [16]. The samples (1.00 × 1.00 × 1.50 cm³) were put into 18 mm NMR tubes for determination. Each sample was scanned 16 times at 2 s intervals with 3000 echoes in total. After the original data were normalized, the transverse relaxation time \( (T_2) \) was measured using a Carr-Purcell-Meiboom-Gill pulse train and CONTIN algorithm.

2.6. Color

After the saucing chicken gizzards were cooled, the surface water was dried with filter paper, and the color of the internal cross-section was measured after the surface skin tissue of the chicken gizzards was cut. A ZE-6000 Color Testers (Juki Corp, Tokyo, Japan) was used for measuring the lightness \( (L^*) \), redness \( (a^*) \) and yellowness \( (b^*) \) values as described by Li et al. [17]. Before the measurement, a white reference tile \( (L^* = 95.26, a^* = -0.89, b^* = 1.18) \) was used to calibrate the instrument. The results were shown as the \( L^*, a^* \) and \( b^* \), and the total color difference \( (\Delta E) \) and chroma \( (C^*) \) were calculated as follows:

\[
\Delta E = \left[ \left( L_0^* - L^* \right)^2 + \left( a_0^* - a^* \right)^2 + \left( b_0^* - b^* \right)^2 \right]^{1/2}
\]

\[
C^* = \left( a_0^2 + b_0^2 \right)^{1/2}
\]

where \( L_0^*, a_0^* \) and \( b_0^* \) were measured from the samples; \( L^*, a^* \) and \( b^* \) were measured from the standard whiteboard.

2.7. Shear force

The method for determining the shear force was according to Tomisaka, Ahhmed, Tabata, Kawahara, and Muguruma [18] and Du et al. [3] with a slight modification. The shear force of the samples (1.00 × 1.00 × 1.50 cm³) was measured using the A/MORS probe of a texture analyzer (Stable Micro System, TA: XT2I, UK) and a total of six cubes for each treatment were prepared for shear force analysis. The test speed was 2.00 mm/s and the arm of force was 30.0 kg. The trigger force was 20.0 g. The compression distance in the direction of vertical muscle fiber was 5 mm.

2.8. Texture profile analysis (TPA)

TPA (springiness, hardness and chewiness) was performed with a texture analyzer (Stable Micro System, TA: XT2I, UK) as described by Zou et al. [6] with slight modifications. The samples were cut into cubes of 1.00 × 1.00 × 1.50 cm³, and a total of six samples for each treatment were prepared for TPA analysis. The P50 probe was used for two compression tests with an interval of 5 s. Other testing parameters were as follows: pre-test speed was 1.50 mm/s, test speed was 1.50 mm/s, post-test speed was 10.00 mm/s, and auto force was 10.0 g.

2.9. Flavor

The flavor analysis was used a PEN3 E-nose (Airsense Analytics GmbH, Schwerin, Germany) including 10 sensor array units according to Yin et al. [19]. The information of 10 sensor array units is as follows: W1C, W5S, W3C, W6S, W5C, W1S, W1W, W2S, W2W and W3S. 3 g of minced saucing chicken gizzards were placed in a 20 mL headspace vial and heated in a water bath at 40 °C for 20 min. Processed pure air was used as a carrier gas to clean the sensor array to cause the signal response to return to zero; then, the sample was measured using an injection volume of 200 μL. The measurement phase lasted for 60 s.

2.10. Statistical analysis

Three independent batches of chicken gizzards (replicates) were prepared. For each batch, measurements of related traits were measured...
three times as technical repetition at room temperature (23 ± 2 °C). One-way analysis of variance (ANOVA) was used for the data analysis and means were compared by the Duncan test using IBM SPSS Statistics 25 to determine that the difference was statistically significant (P < 0.05). Hierarchical cluster analysis (HCA) was conducted among all characteristics (yield, WHC, moisture distribution, color, shear force, texture and flavor properties) of saucing chicken gizzards treated via R software (version 3.6.3, Tsinghua University, Beijing, China) to determine similarities and differences among different samples.

3. Result and discussion

3.1. Yield

The yield of meat products is the ratio of the weight of the product to the raw material to be processed, and its improvement mainly depends on the WHC of the muscle [21]. The effects of ultrasound-assisted saucing on the yield of chicken gizzards are shown in Fig. 1. With the prolonging of the saucing time, the yield of all samples showed a decreasing trend. The decrease in the yield may be due to the denaturation of the protein in chicken gizzards during the saucing process, which causes muscle fibers and connective tissue to shrink, resulting in the reduction in fiber gaps. The reduction in fiber gap would lead to a decrease in water storage capacity, resulting in water loss [22]. Serrano, Librelotto, Cofrades, Sanchez-Muniz, and Jimenez-Colmenero [23] reported that the denaturation of protein would lead to the release of water bound by chemical bonds in the protein during the cooking process, causing an increase in the cooking loss, which would also lead to a decline in the yield.

When the saucing time was the same, the yield of the ultrasound group was higher than that of the non-ultrasound group. Especially, when the saucing time reached 40 min and 50 min, the yield of the ultrasound group increased by 5.07% and 4.83% compared with the non-ultrasound group. This phenomenon may be due to the cavitation effect of ultrasound could effectively destroy the structure of myofibrils, so that more water can be contained between the muscle fibers, thereby improving the water retention of the muscle fibers [24]. Therefore, the ultrasound group has lower water loss and higher yield than that of the non-ultrasound group for the same saucing time. In addition, ultrasound pretreatment may increase the degradation of protein, change the microstructure of meat products, and further promote the infiltration of salt and spices in the saucing process, thereby increasing the yield [25].

3.2. Water holding capacity

WHC refers to the ability of the muscle to retain its inherent water when subjected to external forces (cutting, pressing, grinding, heating, etc.) [26]. The effects of ultrasound-assisted saucing on the WHC of chicken gizzards are displayed in Fig. 2. With the prolonging of the saucing time, the WHC of all samples significantly reduced (P < 0.05). This phenomenon can be explained that the saucing temperature increased with the extension of the saucing time, causing the denaturation of myofibrillar protein and the contraction of muscle fibers, which leads to the loss of water in the muscle, resulting in the decline in water retention [27]. Besides, during the heating process, the thermal denaturation of proteins leads to the change of molecular conformation, resulting in the rupture of hydrogen bonds between protein subunits, the extension of protein structure, and the exposure of hydrophobic residues wrapped in the protein, which reduces the hydration capacity of proteins, thus causing the decrease in water holding capacity [28].

When the saucing time was 20, 30, 40 and 50 min, the WHC of the ultrasound group was increased by 1.05%, 0.97%, 0.67% and 0.38% compared with the non-ultrasound group, respectively. It may be due to the fact that ultrasound could improve the ability of muscle fiber to bind water, thus reducing the cooking loss and improving the WHC of muscle [24]. Moreover, Zou et al. [25] believed that ultrasound treatment could promote the enrichment of salt-soluble protein on the surface of the chicken breast, thereby increasing the ability of the muscle surface to prevent water from spreading out.

3.3. Moisture distribution

The moisture distribution of the saucing chicken gizzards was measured by LF-NMR (described in Fig. 3). The T2 relaxation time of the samples has three peaks (T2a, T21, T22), which represent different water states: (0–10 ms) bound water; (10–100 ms) immobilized water; (100–1000 ms) free water [29]. In general, the shorter the T2 relaxation time, the tighter the bond between water and macromolecules. P2 represents the percentage of the integral area of each water division curve relative to the total area [16].

As shown in Fig. 3A, the T2a, T21 and T22 of all samples gradually shorten with the prolongation of saucing time. Scussat et al. [30] also found that increasing the cooking temperature could reduce the relaxation time. With the extension of the saucing time, P2a had no significant changes (P > 0.05), P21 significantly increased, and the change in P22 was opposite to P21 (P < 0.05). The increase in P21 and the decrease in T2 demonstrated that free water and immobilized water gradually migrated to the surface of the muscle for evaporation. A similar result was reported by Shi et al. [31] for beef jerky, who also confirmed that the migration of free water and immobilized water was associated with myofibrillar protein denaturation and a decrease in the water holding capacity. Heating results in the expansion of protein structure, which further forms aggregates through covalent cross-linking, resulting in the narrowing of myofibrillar protein network space and the generation of moisture channels of various sizes, thus leading to moisture migration through the moisture channels [32,33].

Fig. 1. Effects of ultrasound-assisted saucing on the yield of chicken gizzards. The means in the yield with different lowercase letters (a-f) differ significantly (P < 0.05).

Fig. 2. Effects of ultrasound-assisted saucing on the water holding capacity of chicken gizzards. The means in the water holding capacity with different lowercase letters (a-f) differ significantly (P < 0.05).

Fig. 3. Effects of ultrasound-assisted saucing on the distribution of transverse relaxation time (T2) (A) and P2 (T2 peak ratio) (B) of chicken gizzards. The means in the same index with different lowercase letters (a-f) differ significantly (P < 0.05). C: Non-ultrasound; U: ultrasound.
At the same saucing time, $T_{21}$ and $T_{22}$ of the ultrasound group were lower than those of the non-ultrasound group. This result indicates that ultrasound pretreatment can increase the binding strength of water and macromolecules, thus improving the water retention of muscle fibers [24]. Meanwhile, after ultrasound pretreatment, $P_{21}$ significantly decreased and $P_{22}$ significantly increased ($P < 0.05$). The cavitation effect of ultrasound enlarged both the space between muscle fibers and the gap between cells, so that more water can be accommodated, thus improving WHC [24].

3.4. Color

The color of cooked meat is considered a reliable indicator of its eating quality [34]. The effects of ultrasound-assisted saucing on the color of chicken gizzards are displayed in Fig. 4. With the prolonging of the saucing time, the $L^*$ and $a^*$ values of all samples significantly decreased ($P < 0.05$), and the $b^*$ values showed an increasing trend. Oz and Celik [35] also found that the cooking process reduced the $L^*$ and $a^*$ values of goose meat, while it increased the $b^*$ values. As the heat progresses, myosin (the main protein of myofibrillar protein) heads and tails denature successively, causing cross-linking of myosin to occur in head-head, tail-tail, and head-tail, reducing the binding ability of protein and water [36]. The loss of water in the muscle causes a decrease in the surface refractive index, thereby resulting in a decrease in the $L^*$ value [37]. Besides, Rahimi, Kashaninejad, Ziaiifar, and Mahoonak [38] believed that the increase in meat temperature and loss of water content would enhance the lard reaction, which promoted the formation of brown pigments, leading to the decrease in $L^*$ value. The decrease in $a^*$ value is due to the oxidation of myoglobin (bright red) to metmyoglobin (reddish-brown) [11]. Furthermore, the oxidation of lipid and the penetration of spices during heating are the main reasons for the increase in the $b^*$ value [39].

At the same saucing time, there was no significant difference in the $L^*$ value between the ultrasound and the non-ultrasound groups ($P > 0.05$). Meanwhile, compared with the non-ultrasound group, ultrasound treatment significantly reduced the $a^*$ value and increased the $b^*$ value ($P < 0.05$). Sun, Kong, Liu, Zheng, and Zhang [40] reported that ultrasound would decompose water to produce free radicals, which resulted in the oxidation of muscle pigment, leading to the increase in $b^*$ value and the decrease in $a^*$ value. In addition, ultrasound cavitation loosens muscle fibers, which may promote the entry of water and spices, leading to the dissolution of some pigments. Therefore, ultrasound pretreatment could promote the penetration of the soup during the saucing process of chicken gizzards, which implied that the time of ultrasound-assisted saucing might be shorter than that of traditional saucing when the same saucing effect of the chicken gizzards was achieved.

$C^*$ is an indicator of color saturation that reflects the concentration of myoglobin and its denaturation [41]. The higher the $C^*$, the higher the myoglobin concentration and the lower the degenerated myoglobin content [42]. The $C^*$ value of the samples decreased gradually with the extension of the saucing time, indicating that long-term high-temperature cooking increased the degeneration of myoglobin. Ultrasound treatment reduced the $C^*$ value of the samples with the same saucing time. The decrease in $C^*$ value may be due to the loosening of muscle structure and formation of channels in the muscle caused by ultrasound treatment, which promotes myoglobin dissolution, thus leading to the decrease of myoglobin concentration, which is also consistent with the result of $a^*$ value. The $\Delta E$ value is a common method to evaluate the color difference between samples [43]. With the prolonging of the saucing time, the $\Delta E$ value of all samples significantly increased ($P < 0.05$), suggesting that the long period of saucing caused the darker color of chicken gizzards. The result is likely to be that the long period of saucing promotes the infiltration of the soup and seasoning, which darkens the color of the chicken gizzards. The $\Delta E$ value of the ultrasound group was lower than that of the non-ultrasound group when the saucing time was the same, indicating that the color of the ultrasound group was lighter than that of the non-ultrasound group, which corresponded to $a^*$ value. Similarly, ultrasound-assisted curing was reported to decrease the $\Delta E$ of pork loin muscle [44].

3.5. Shear force

The shear force is an intuitive index to characterize the tenderness of meat products [45]. Tenderness is considered to be the most important palatability factor when consumers evaluate meat quality [46]. The effects of ultrasound-assisted saucing on the shear force of chicken gizzards are displayed in Fig. 5A. With the increase of the saucing time, the shear force of all samples gradually increased. The increase in shear force is due to the degeneration of proteins, myofibrils and connective tissue (collagen) caused by heating, resulting in the contraction of the fibers [47]. The denaturation of collagen strengthens the original curled collagen fibers, resulting in an increase in the amount of collagen per unit area, which leads to an increase in tension and ultimately to an increase in shear force [48]. Tornberg [49] noted that the moisture loss of minced meat increased with the increase in temperature, which improved its toughness.

When the saucing time was the same, the shear force of chicken gizzards under ultrasound pretreatment was significantly lower than that of the non-ultrasound group ($P < 0.05$). This result implies that ultrasound pretreatment improves the tenderness of saucing chicken gizzard. The reason for this phenomenon is that ultrasound-induced structural damage to the lysosome results in the release of calcium-activated proteases that degrade myofibrillar skeletal proteins such as tropomyosin, titin, and nebulin [8]. On the other hand, the cavitation effect caused by ultrasound can destroy the integrity of connective tissue, leading to the fracture of the connection between collagen fibers and weakening of the intramural connective tissue structure, so as to achieve the tender effect [3]. In addition, Li, Wang, Sun, Pan, and Cao [50] thought that ultrasound could reduce the shear force of goose meat by destroying the integrity of the myofibrillar.

![Fig. 4. Effects of ultrasound-assisted saucing on the color parameters of chicken gizzards. The means in the same index with different lowercase letters (a-h) differ significantly ($P < 0.05$). C: Non-ultrasound; U: ultrasound.](image)

![Fig. 5. Effects of ultrasound-assisted saucing on the shear force (A), hardness (B), springiness (C) and chewiness (D) of chicken gizzards. The means in the same index with different lowercase letters (a-f) differ significantly ($P < 0.05$).](image)
3.6. Texture profile analysis

The effects of ultrasound-assisted saucing on the hardness, springiness, and chewiness of chicken gizzards are shown in Fig. 5. With the increase of the saucing time, the hardness and chewiness of the chicken gizzards all gradually increased, while the springiness decreased continuously. This result is mainly due to the degeneration of protein, the tightening of muscle fibers, and the loss of water of the chicken gizzard during the saucing process, which would cause the texture of the samples to become hard, leading to an increase in hardness and chewiness [49]. Botinestean et al. [47] also suggested that the hardness of beef steaks increased with the increase in cooking time. The decrease in springiness of chicken gizzards may be due to the increase of water loss with the prolonging of saucing time, resulting in the decrease of the water content of samples. This was different from the report by Park, Lee, Oh, Kim, and Choi [51], who found that the springiness of chicken breast meat increased with the extension of cooking time when cooking at 60 °C. The reason for this phenomenon might be the difference in cooking temperature.

When the saucing time was the same, the hardness and chewiness of the ultrasound samples were significantly lower than those of the non-ultrasound group (P < 0.05), while the change in springiness was the opposite. This was consistent with the study of Zhang et al. [11], who suggested that ultrasound treatment reduced the hardness and chewiness of spiced beef. The results may be explained that ultrasound pretreatment destroys the integrity of the muscles, increasing the gap between the fibers, and further enhancing the water retention of the fibers, thereby improving the tenderness and springiness of chicken gizzards [9]. Therefore, ultrasound pretreatment could maintain better texture profiles during the saucing of chicken gizzards.

3.7. Flavor

The electronic nose is an effective tool for distinguishing odor characteristics, which can obtain comprehensive information related to volatile compounds in the sample [52]. The response values of the electronic nose of chicken gizzards with different saucing time after ultrasound pretreatment are described in Fig. 6A. As the extension of the saucing time, the response values of W1C (aromatic compounds), W3C (ammonia, aromatic molecules), W5C (short-chain alkanes), and W2S (alcohols, aldehydes and ketones) sensors of all samples increased, indicating that saucing process might increase the content of aromatic hydrocarbons, ammonia, short-chain alkanes, alcohols, aldehydes and ketones. On the contrary, the signal intensities of W6S (hydrogen compounds), W1S (methyl compounds) and W3S (long-chain alkanes) sensors decreased, indicating that the content of hydrogen, methyl compounds and long-chain alkanes decreased during the saucing process. Meanwhile, the signal intensities of W5S (nitrogen oxides), W1W (sulphides) and W2W (organic sulphides) sensors had no significant difference (P > 0.05), which showed that part of volatile components (nitrogen oxides, sulphides and organic sulphides) content of chicken gizzards remained almost unchanged after saucing. When the saucing time was the same, the response values of W1C, W5C and W2S of the samples treated with ultrasound were higher than those of the non-ultrasound group, while the response values of W6S and W1S were lower than those of the non-ultrasound group. Zou et al. [53] also found that ultrasound treatment increased the relative content of volatile flavor substances in spiced beef, especially aldehydes, alcohols, and ketones. It may be due to the fact that ultrasound pretreatment promotes the degradation of proteins and lipids into small molecules, which generate flavor compounds such as aldehydes, ketones, esters and free amino acids through secondary oxidation of lipids [11,54]. These results showed that ultrasound pretreatment could improve the flavor of saucing chicken gizzards.

The principal component analysis (PCA) of the electronic nose flavor sensor is shown in Fig. 6B. PC1 and PC2 accounted for 59.92% and 26.11% of the total variation, respectively, and the total of the two principal components reached 86.03% (>85%), which implied that the two principal components basically contained enough information to reflect the total variance of the entire dataset [55], C-20 (saucing for 20 min without ultrasound pretreatment), C-30 (saucing for 30 min without ultrasound pretreatment), and U-20 (saucing for 20 min with ultrasound pretreatment) were all on the negative axis of PC1 and related to W6S, W3S, W1S, and W2W sensors. C-40 (saucing for 40 min without ultrasound pretreatment), C-50 (saucing for 50 min without ultrasound pretreatment), U-30 (saucing for 30 min with ultrasound pretreatment), U-40 (saucing for 40 min with ultrasound pretreatment) and U-50 (saucing for 50 min with ultrasound pretreatment) were all clustered on the positive axis of PC1 and related to other sensors. The results showed that these sensors could effectively identify the samples treated with different saucing times (between non-ultrasound and ultrasound groups). Among them, the electronic nose data distribution of the C-50 and U-30 groups was relatively close, demonstrating that they have similar odors, which indirectly implied that ultrasound could improve the processing efficiency by shortening the saucing time without affecting the flavor.

3.8. Correlation analysis

Hierarchical cluster analysis (HCA) results are usually represented by heat maps, which describe multivariate correlations among different samples in a hierarchical manner [56]. As described in Fig. 7, in cluster 1, C-30, C-40, C-50, U-30, U-40 and U-50 groups had an up-regulation trend in texture (hardness and chewiness), shear force, b* value, P21 and flavor properties (W1W, W5S, W2S, W3C, W1C and W6S), while a
slight down-regulation trend was observed in the C-20 and U-20 group. In addition, C-20 and U-20 groups (cluster 2) presented an impact toward up-regulating yield, In addition, C-20 and U-20 groups (cluster 2) presented an impact to slight down-regulation trend was observed in the C-20 and U-20 group. However, compared with the U-40 and C-30 groups, the U-30 group showed an apparent down-regulation trend for shear force, hardness and chewiness and a higher up-regulation trend in WHC and yield, indicating that the U-30 group was an appropriate treatment for the improvement of saucing chicken gizzards quality.

4. Conclusions

Overall, ultrasound-assisted saucing could effectively raise the yield while improving the WHC and tenderness of chicken gizzards. It was worth noting that ultrasound-assisted saucing also improved the flavor of chicken gizzards, and the U-30 group was the best. Therefore, as a green and eco-friendly physical tenderization technology, ultrasound is effective in improving the quality of saucing products (especially chicken gizzards). In addition, in terms of economics, ultrasound treatment can shorten the saucing time without affecting product quality, and provides guidance for the industrial production of saucing products.

CRediT authorship contribution statement

Haijing Li: Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft. Xia Feng: Investigation. Shuo Shi: Software, Data curation. Xu Wang: Conceptualization, Resources, Validation. Xiufang Xia: Conceptualization, Writing – original draft, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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