Original Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.119222

Effects of different sterilization methods on sensory quality and lipid oxidation of Dezhou braised chicken

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Abstract

This work studied the effects of different time and temperature combinations [100 °C for 50 min (T1), 110 °C for 50 min (T2), 118 °C for 50 min (T3) and 121 °C for 30 min (T4)] of sterilization on the sensory quality and lipid oxidation of Dezhou braised chicken. Compared to T1, T3 and T4 groups, the T2 group had the highest colour and lower hardness. The principal component analysis (PCA) of the electronic-tongue results showed that there were distinct differences in taste between the treatment groups. Free amino acids (FAA) analysis showed that the T2 group had the highest amino acid contents. In summary, the T2 might be a more reasonable sterilization condition for Dezhou braised chicken, due to its positive effects on maintaining sensory quality. The results of this study could guide Dezhou braised chicken industry to produce better quality products.

Keywords: Dezhou braised chicken; sterilization method; sensory quality; lipid oxidation.

Practical Application: By researching the effects of sterilization on the quality of braised chicken, indicated 110 °C for 50 min might be a more reasonable sterilization condition.

1 Introduction

Dezhou braised chicken is a traditional Chinese cuisine with 300 years of history. Dezhou braised chicken is well-liked by Chinese people due to its pleasing color, moderate hardness, and delicious smell (Duan et al., 2015). Several scientific studies have been conducted on this traditional Chinese meat product. Liu et al. (2017) used electronic tongues to study the taste of Dezhou braised chicken and found that hypoxanthine nucleotides Glu, Lys and NaCl play an important role in the flavour attributes of the final product. Yao et al. (2022) used headspace-gas chromatography-flow spectrometry to access the volatiles formed during the processing of Dezhou braised chicken, and they detected a total of 37 volatile compounds, including aldehydes.

Products made from braised meats may suffer from negative impacts due to microbial growth, such as color changes and disagreeable aromas (Wang et al., 2016). Heat treatment applications usually include pasteurization (below 100 °C) and high-temperature sterilization (above 100 °C). Sterilization can kill pathogenic bacteria and spoilage microorganisms in products. To extend the shelf life, sterilization technologies have also been widely used in meat products. At present, cold sterilization has attracted people's attention, such as radiation and ultraviolet light (Cho & Ha, 2019; Long et al., 2021). Pasteurization at 65 Fahrenheit for 30 s was sufficiently effective to decrease the mean Aerobic Plate Counts (APC) for a significant inactivation (approx. 4.5 log reductions) in pomegranate juice, and the microbial load in fresh pomegranate juice was reduced from 4.0 log 10 $CFUmL^{-1}$ to 1.0 log 10 $CFUmL^{-1}$ after pressurization at 400 MPa for 5 min (Putnik et al., 2019). However, considering the low cost and convenience of sterilization equipment, high-temperature sterilization is the first choice in meat processing.

Different sterilization treatments will have different effects on the texture, colour and flavour of meat products (Xu et al., 2018; Abdulhameed et al., 2016; Zhu et al., 2019). The study found that ultrasonic sterilization (US) and high-temperature sterilization (HTS) reduced the hardness and viscosity of canned flavor crab meat sauce (Cho & Ha, 2019), and Nano-ZnO, combined with radio-frequency (ZNCRF) 30 min pasteurization and HPS sterilization, both resulted in a decrease in springiness, cohesiveness, chewiness and resilience in twice-cooked pork (Xu et al., 2018). With the increase in the sterilization treatment temperature, the content of volatile terpenoids significantly decreased.

High-temperature sterilization can accelerate the degradation of free amino acids and the rate of lipid oxidation. The free amino acid content can be an important indicator when assessing the taste quality of Dezhou braised chicken. Lipid oxidation is one of the main factors in food deterioration. The lipid oxidation of meat products will produce an unpleasant taste and volatile odors, and the texture and function of muscles will deteriorate, leading to a decrease in edible nutritional quality (Ortiz et al., 2013). The CD and TBARS indexes can be used to evaluate lipid oxidation. The impact of sterilization temperature and time on

Received 01 Nov., 2022
Accepted 22 Dec., 2022
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the eating quality of food was less studied, despite being the most commonly used technique for extending the shelf-life of food.

This study aims to assess and analyze the effects of different sterilization methods on the quality of Dezhou braised chicken. The physicochemical and sensory characteristics of meat are evaluated in terms of color, texture, taste profile, and lipid oxidation values to form integral predictions of the Dezhou braised chicken's quality. Thus, it is necessary to explore a reasonable sterilization treatment based on the current conditions used by companies. The results of this study will allow for the industrial production of high-quality Dezhou braised chicken.

2 Materials and methods

2.1 Chemicals

The 17 amino acid mixed standard (13-08391, Wako, Tokyo, Japan) was used. Other analytical grade reagents were obtained from Tianjin Chemical Reagent Co., Inc. All chemicals used in the present study were analytical or high-grade.

2.2 Preparation of samples

To ensure that the products belonged to the same batch, Dezhou braised chicken was provided by Shandong Dezhou Braised Chicken Co., Ltd. Five groups were selected, all of which are currently commercially available, marketed Dezhou braised chicken products. The control group had a shelf life of 15 days, and the sterilized group had a shelf life of more than 45 days. T1 was sterilized at 100 °C for 50 min; T2 was sterilized at 110 °C for 50 min; T3 was sterilized at 118 °C for 30 min; T4 group was sterilized at 121 °C for 30 min; the control was without sterilization (untreated group).

2.3 Color

The meat sample was evenly placed into a transparent plastic bag, and the color was measured (L^*, a^* and b^*) using a colorimeter (CR-400, Konica Minolta Sensing Inc., Osaka, Japan). Six replicates were used for each sample.

2.4 Texture

Samples were analyzed using a texture profile analysis (TPA) to evaluate the texture of the chicken, following the method applied by Endrit, with minor modifications (Hasani et al., 2022). The P-35 cylinder probe and texture analyzer (Model TMS-Pilot, FTC) were used the procedure was as follows: compress the chicken to 50% of its original height in two cycles at a speed of 1 mm/s (velocity of 100 N) to obtain a force–time curve. Finally, the data were processed using the Windows (Stable Micro System) texture expert software to evaluate TPA properties: hardness, cohesiveness, springiness, adhesiveness, chewiness and gumminess. Six replicates were used for each sample.

2.5 Electronic tongue

SA402B E-tongue (Beijing Ying Sheng Heng Tai Technology Company, TS-5000Z, China) was used to evaluate the effect of sterilization on the taste of chicken samples, according to the detection method of Tan et al. (2022), with minor modifications. The SA402B E-tongue includes five test sensors and two reference sensors. A total of 50 g of chicken meat samples was weighed and placed into a beaker; then, a total of 200 mL of ultrapure water was added and; stir well. Finally, taste analysis application software translated the E-tongue detection data to taste values. Three replicates were used for each sample.

2.6 Free amino acid composition

The effect of sterilization treatment on amino acid composition in chicken was analyzed according to the detection method of Bai et al. (2021). A total of 1 g of chicken samples was placed into a 25 mL hydrolysis tube, 16 mL of 6 mol HCl was added, and this was mixed well. The solution was hydrolyzed at 110 °C for 22 h under nitrogen atmosphere. Finally, ultrapure water was added to dilute to 50 mL. A total of 1 mL of dilution was dried under nitrogen, and re-dissolved with 1 mL of 0.02 mol HCl. After that, it was filtered through a 0.22 μm water phase filtration membrane, the filtrate was taken, and an automatic amino acid analyzer was used for detection (LA8080, Hitachi Ltd, Tokyo, Japan). The results are shown as g/100 g. Three replicates were used for each sample.

2.7 Lipid oxidation analysis

Conjugated Diene (CD) measurement

The effect of sterilization treatment on chicken CD was analyzed according to Roldan's detection method (Roldan et al., 2014). A total of 1 g of chicken minced sample was placed in 10 mL of distilled water, mixed well, and then homogenized with an XHF-D homogenizer (Ningbo Xinzhi Biotechnology Co., Ltd., Zhejiang, China) for 1 min. Subsequently, 0.5 mL of suspension was taken, 5 mL of extracting solution (3:1 v/v hexane/isopropanol) was added, and this was stirred with a vortex mixer for 1 min to mix well. Then, at 4 °C, 3500 × g, this was centrifuged for 5 min (4-16KS centrifuge, Sigma, Darmstadt, Germany). Finally-the supernatant's absorbance was determined at 233 nm with a photometer (UV-2800A, Shimadzu, Tokyo, Japan). Three replicates were used for each sample.

Thiobarbituric Acid Reactive Substances (TBARS) measurement

The TBARS in chicken was analyzed according to the detection method of Araújo et al. (2022), with some modifications. A total of 10 g of chicken minced meat was taken, and 20 mL of 20% trichloroacetic acid (TCA) was added and mixed well, before 6000 × g was homogenized for 1 min with a homogenizer. Subsequently, at 4 °C, 5500 × g, this was centrifuged for 10 min. A total of 5 mL of supernatant, was taken, 5 mL of 0.02 mol thiobarbituric acid (TBA) was added, and 5 mL of TCA was mixed with the same volume of 0.02 mol TBA as a blank. This was mixed well and then heated for 20 minutes in a pot of boiling water. The solution was cooled to room temperature and its absorbance was detected at 532 nm and 600 nm with a spectrophotometer. Three replicates were used for each sample.

2.8 Statistical analysis

Data analysis was accomplished using Microsoft Excel, and the results are expressed as the means ± standard deviations (SDs). Analysis of variance (ANOVA) and the post hoc Duncan test were used to examine the differences between the types. Differences were considered significant at $p < 0.05$. Principal component analysis (PCA) plots and radar plots were produced through Origin 2022.

3 Results and discussion

3.1 Color

Color is one of the most significant factors that affects how people view the quality and safety of meat (García-Segovia et al., 2007). Changes in the color characteristics of meat products may result from myoglobin denaturation and oxidation, Maillard reactions, packaging, or pH changes, among other potential causes (Pulgar et al., 2012). Table 1 showed the effects of various sterilization methods on the color of Dezhou braised chicken ($p < 0.05$).

L^* value is an important index to describe the brightness of the sample (Jiao et al., 2022). Compared to the control, the sterilization groups showed an increased lightness (L^*), except for T4 (34.04), due to myoglobin changes during denaturation (Hunt et al., 1999). The results demonstrated that, compared to the T1, T2, and T3 conditions, the T4 condition had a significantly lower lightness (L^*) value. This may be due to the reduced water-holding capacity of Dezhou braised chicken caused by sterilization, which reduces the surface reflectivity and affects the optical properties of meat (Arvanitoyannis et al., 2011). Redness (a^*) values were between 10.17 and 16.48. Compared to the control, the sterilization groups showed a higher a^*, except for T4. In our study, under T1 and T2 treatments, we found no significant difference in redness. From T2 to T4, the a^* value gradually decreased sterilization. This may be due to the fact that sterilization causes a loss of moisture. It has also been shown that pH was negatively correlated with myoglobin degeneration (Van Laack et al., 1996). In addition, sterilization increased lipid oxidation (Panseri et al., 2018). This might have also been connected to the oxidation denaturation of myoglobin (Lino et al., 2022). Yellowness is an intuitive performance regarding meat discoloration. Compared to the control, the sterilization groups showed higher yellowness (b^*). Yellowness has been shown to be associated with lipid and protein oxidation (Wang et al., 2020). The effects of lipid oxidation on the formation of yellow pigments in meat are related to the non-enzymatic browning reactions between lipid oxidation products and the amine in the proteins, or in the phospholipid head groups (Xia et al., 2009). However, all the treatment groups showed no significant difference in the b^*.

3.2 Texture properties

One of the most important quality restrictions that must be met to guarantee product acceptability is texture. The data of all texture property parameters (hardness, adhesiveness, cohesiveness, springiness, gumminess, and chewiness) of Dezhou braised chicken, with various sterilization times and temperatures, are shown in Table 2 ($p < 0.05$). Consumers placed the highest importance on the hardness of all the tested texture parameters, since this affects the commercial worth of meat products (Nurul et al., 2010). Compared to the control, the sterilization groups showed a lower hardness, expect for T1. The highest hardness value (45.37 N) was obtained in sterilized treated at 100 °C for 50 min (T1), which was significantly higher compared to other sterilization groups (T2, T3, and T4). There was no significant difference in hardness between T2, T3, and T4. This is because increased sterilizing temperatures cause collagen to dissolve and lead to structural alterations that cause muscle fibers to loosen (Jiang et al., 2018). There were no significant differences between the control and treated groups regarding adhesiveness and springiness. Previous studies also reported no difference in the springiness of the braised beef following different sterilized methods (Wang et al., 2019). Compared to the control, the sterilization groups showed a higher cohesiveness, expect for T1. For older consumers, chewiness and gumminess are two other crucial textural qualities, in addition to hardness. According to the results presented in Table 2, gumminess and chewiness were increased in the sterilized treated samples in comparison with the control, except for T4. Older consumers will be more likely to choose meats that have less gumminess and chewiness, and sterilization-treated meats provide important textural attributes (Forde et al., 2013). With the same treatment time, the gumminess and chewiness were highest under T3 conditions.

3.3 Electronic tongue

A radar graph was also used to illustrate the changes in various tastes with the use of different temperature and time combinations (Figure 1a). There were no significant differences in bitterness, astringency, aftertaste B, aftertaste A, umami, richness and saltiness. However, a small distinction was observed in terms of sourness. We can see that the umami and sourness sensors had the largest and smallest contributions with different treatments. However, we still need to use the proper sterilizing temperature and duration when preparing Dezhou braised chicken to avoid any potential negative taste-related effects of sterilization at high temperatures for an extended period of time.

Electronic tongues transform electrical signals into savor signals to convey taste information of food. Due to their low threshold for sensation, subjectivity in sensory assessments can

Table 1. Changes in colour of Dezhou braised chicken with different sterilization methods.

	Control	T1	T2	T3	T4
L^*	34.04 ± 1.37^d	54.22 ± 0.43^b	58.22 ± 1.42^a	50.62 ± 1.67^c	32.04 ± 1.07^d
a^*	10.17 ± 1.74^c	14.93 ± 1.29^a	16.48 ± 0.39^a	12.83 ± 0.78^b	10.82 ± 2.09^c
b^*	15.64 ± 3.25^b	33.00 ± 2.14^a	32.35 ± 1.14^a	31.47 ± 1.71^a	31.57 ± 3.47^a

Different letters in the same peer indicate significant differences between different sterilization treatments ($p < 0.05$).

Table 2. Changes in textural properties of Dezhou braised chicken with different sterilization methods.

	Control	T1	T2	T3	T4
Hardness (N)	39.81 ± 2.49^{b}	45.37 ± 1.89^{a}	32.84 ± 3.64^{c}	31.81 ± 3.89^{c}	30.10 ± 5.45^{c}
Adhesiveness (mj)	0.60 ± 0.36^{a}	0.38 ± 0.23^{a}	0.31 ± 0.14^{a}	0.45 ± 0.31^{a}	0.31 ± 0.10^{a}
Cohesiveness (Ratio)	0.28 ± 0.02^{b}	0.29 ± 0.04^{ab}	0.32 ± 0.03^{a}	0.33 ± 0.03^{a}	0.32 ± 0.03^{a}
Springiness (mm)	0.60 ± 0.10^{b}	0.64 ± 0.17^{b}	0.71 ± 0.18^{a}	0.68 ± 0.26^{ab}	0.61 ± 0.11^{b}
Gumminess (N)	11.03 ± 0.85^{bc}	13.23 ± 2.24^{b}	11.45 ± 1.79^{c}	19.06 ± 2.73^{a}	9.47 ± 2.26^{c}
Chewiness (mj)	6.68 ± 1.50^{b}	8.58 ± 2.84^{b}	7.96 ± 1.97^{b}	12.97 ± 5.21^{a}	5.69 ± 1.5^{b}

Different letters in the same peer indicate significant differences between different sterilization treatments ($p < 0.05$).

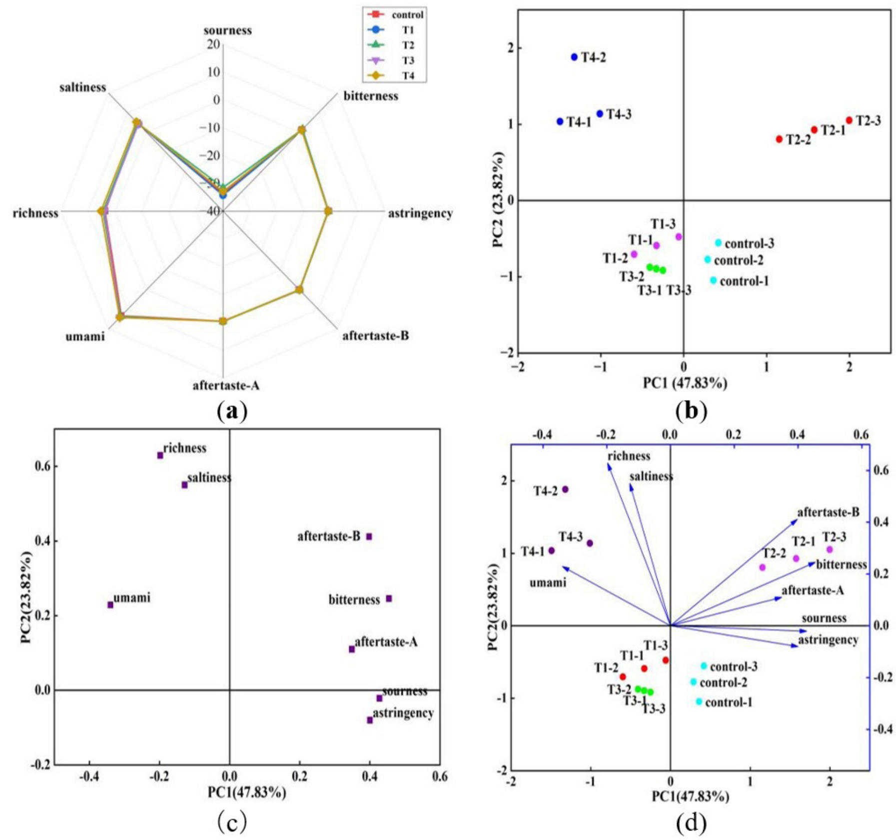

Figure 1. Electronic-tongues analysis: (a) radar graph of Dezhou braised chicken with different sterilization methods; (b) score plot (PCA) of Dezhou braised chicken with different sterilization methods; (c) loading plot (PCA) of the taste properties; (d) Biplot (PCA) of E tongues for Dezhou braised chicken with different sterilization methods.

be ignored (Zoldan et al., 2014). As shown in Figure 1b, the cumulative contribution rates of the first principal component (PC1) (47.83%) and the second principal component (PC2) (23.82%) were 71.65%. The T2 and T4 groups were far from one another, indicating different taste characteristics, whereas the control, T1 and T3 groups were close to one another, showing similar taste. The control, T1 and T3 groups were far from T2 and T4 groups, showing that the sterilization process drastically altered the flavor of the chicken. Figure 1c shows a loading plot (PCA) of the taste properties. Figure 1c shows that PC1 was positively related to bitterness, astringency, aftertaste-B, aftertaste-A and sourness, and negatively related to umami, and PC2 was positively related to richness and saltiness. Figure 1d shows a biplot (PCA) of E tongues for Dezhou braised chicken. The T2 and T4 groups stood out: the T2 group had relatively high bitterness, aftertaste A and aftertaste B, while the T4 group had relatively high umami.

3.4 Free Amino Acid (FAA)

Amino acids play a key role in the creation of the distinctive taste profile of meat products, in addition to being the primary nutritional components (Sforza et al., 2006), including umami taste (Glu and Asp), sweet taste (Gly, Thr, Ser, Pro and Ala), and bitter taste (Met, Ile, Arg, Leu, Val and Phe). The effect of different treatments on the FAA content of Dezhou Braised Chicken is summarized in Table 3. Detailed information on the detection and quantification limits of this method for 17 free amino acids can be found in the Supplementary Material. There were significant differences in some FAA content among the five groups ($p < 0.05$). As we can see from Table 3, we detected a total of 17 FAAs in Dezhou braised chicken, and the main FAAs in Dezhou braised chicken were Asp, Glu, Leu, Lys, and Arg, with more than 2 g/100 g in five samples, among which the content of Glu was the highest. Cys content was the lowest in all the samples. The high content of Glu is typical in myosin in chicken, brought about by the hydrolysis of proteins during thermal processing (Kurihara, 2015). Rolls (2009) showed that odor, together with Glu, causes sensations of pleasantness in primates. Compared to the control group, FAA contents were significantly lower in all sterilization groups, except for Cys and Pro. This shows that the treatment caused different levels of FAA loss in Dezhou braised chicken. This result may be attributed to the thermal denaturation of the proteins in the meat product in the event of high-temperature treatment (Martens et al., 1982). In the four different treatment combinations, all free amino acids were highest in the samples treated at 110 °C for 50 min (T2), except for Asp. This means that the loss of free amino acids in Dezhou braised chicken was the least after T2 treatment.

Generally, amino acids serve as the primary building blocks for the flavors found in meat. Umami, sweet, and bitter amino acids in treated groups were decreased compared to the control group. The total amount of bitter amino acids was the highest in all samples (10.36 g/100 g, 7.68 g/100 g, 9.08 g/100 g, 7.67 g/100 g, 7.55 g/100 g, respectively), followed by umami and sweet amino acids. Aromatic amino acids Phe and Tyr were present in very small amounts in the chicken. Glu mainly determines the taste of chicken meat. In addition to Glu, aromatic amino acids are crucial to boosting the umami or salty flavors at sub-threshold quantities, when free acidic amino acids and salt are present (Gheorghe et al., 2021). The decrease in free amino acid content may affect the taste of Dezhou braised chicken, further affecting the consumer enjoyment of Dezhou braised chicken. Therefore, according to the concentrations of free amino acids, it can be concluded that Dezhou braised chicken may taste better under T2 treatment conditions.

In this experiment, nine essential amino acids were detected: Thr, Val, Met, Ile, Leu, Phe, Lys, His and Arg. Eight non-essential amino acids were detected: Asp, Glu, Ser, Gly, Ala, Cys, Tyr and Pro, respectively. Five groups presented total essential amino acid (ΣEAA) values between 11.33 and 15.76 g/100 g and non-essential amino acids (ΣNEAA) values between 10.87 and 14.69 g/100 g. The ΣEAA and ΣNEAA in the control group were the highest, followed by the T2 sterilization treatment. This was the same trend as that of the taste-presenting amino acid contents. The ΣEAA and ΣNEAA contents were significantly lower in the T3 (11.53 g/100 g) and T4 (11.33 g/100 g) groups compared to the T2 (13.72 g/100 g) group. This may be caused by the degradation of amino acids due to the increase in sterilization time or temperature. Lys and Met in EAA were the most and least abundant, respectively. Glu and Cys in NEAA were the most and least abundant, respectively. Lysine is the most susceptible amino acid in intact proteins, because it has a free amino acid group that is readily available to react with

Table 3. Changes in the FAA of Dezhou braised chicken with different sterilization methods (g/100 g).

	Control	T1	T2	T3	T4
Asp	3.07 ± 0.04^{a}	2.26 ± 0.05^{c}	2.61 ± 0.01^{b}	2.21 ± 0.03^{cd}	2.18 ± 0.05^{d}
Glu	5.00 ± 0.07^{a}	3.71 ± 0.04^{c}	4.36 ± 0.01^{b}	3.46 ± 0.04^{e}	3.57 ± 0.07^{d}
Thr	1.42 ± 0.02^{a}	1.05 ± 0.02^{c}	1.22 ± 0.00^{b}	1.03 ± 0.01^{c}	1.02 ± 0.03^{c}
Ser	1.22 ± 0.02^{a}	0.91 ± 0.01^{c}	1.07 ± 0.00^{b}	0.89 ± 0.01^{c}	0.89 ± 0.02^{c}
Gly	1.47 ± 0.02a	1.13 ± 0.02^{d}	1.47 ± 0.00^{a}	1.23 ± 0.01^{c}	1.34 ± 0.03^{b}
Ala	1.90 ± 0.03^{a}	1.42 ± 0.02^{c}	1.68 ± 0.00^{b}	1.40 ± 0.01^{c}	1.42 ± 0.03^{c}
Cys	0.08 ± 0.00^{b}	0.05 ± 0.00^{e}	0.08 ± 0.00^{a}	0.06 ± 0.0^{d}	0.08 ± 0.00^{c}
Val	1.61 ± 0.02^{a}	1.21 ± 0.02^{cd}	1.41 ± 0.00^{b}	1.21 ± 0.01^{c}	1.18 ± 0.02^{d}
Met	0.89 ± 0.01^{a}	0.66 ± 0.01^{c}	0.77 ± 0.00^{b}	0.65 ± 0.01^{cd}	0.64 ± 0.01^{d}
Ile	1.56 ± 0.02^{a}	1.16 ± 0.02^{c}	1.37 ± 0.00^{b}	1.16 ± 0.01^{c}	1.13 ± 0.02^{c}
Leu	2.95 ± 0.04^{a}	2.16 ± 0.04^{c}	2.55 ± 0.00^{b}	2.12 ± 0.02^{cd}	2.09 ± 0.03^{d}
Tyr	1.06 ± 0.02^{a}	0.78 ± 0.01^{c}	0.92 ± 0.00^{b}	0.80 ± 0.01^{c}	0.77 ± 0.03^{c}
Phe	1.26 ± 0.02^{a}	0.94 ± 0.01^{c}	1.11 ± 0.00^{b}	0.96 ± 0.01^{c}	0.95 ± 0.01^{c}
Lys	2.99 ± 0.05^{a}	2.20 ± 0.03^{c}	2.58 ± 0.00^{b}	2.15 ± 0.02^{c}	2.09 ± 0.03^{d}
His	0.99 ± 0.01^{a}	0.75 ± 0.01^{c}	0.84 ± 0.01^{b}	0.68 ± 0.01^{d}	0.67 ± 0.01^{d}
Arg	2.09 ± 0.03^{a}	1.55 ± 0.03^{c}	1.86 ± 0.01^{b}	1.56 ± 0.01^{c}	1.56 ± 0.03^{c}
Pro	0.89 ± 0.02^{b}	0.72 ± 0.01^{d}	0.96 ± 0.01^{a}	0.82 ± 0.01^{c}	0.91 ± 0.01^{b}
Umami	8.08 ± 0.11^{a}	5.97 ± 0.09^{c}	6.97 ± 0.02^{b}	5.67 ± 0.07^{d}	5.75 ± 0.13^{d}
Sweet	6.89 ± 0.11^{a}	5.22 ± 0.06^{e}	6.40 ± 0.02^{b}	5.37 ± 0.06^{d}	5.58 ± 0.10^{c}
Bitter	10.36 ± 0.16^{a}	7.68 ± 0.13^{c}	9.08 ± 0.02^{b}	7.67 ± 0.06^{c}	7.55 ± 0.13^{c}
ΣEAA	15.76 ± 0.23^{a}	11.68 ± 0.18^{c}	13.72 ± 0.03^{b}	11.53 ± 0.10^{cd}	11.33 ± 0.20^{d}
ΣNEAA	14.69 ± 0.22^{a}	10.98 ± 0.14^{c}	13.16 ± 0.04^{b}	10.87 ± 0.12^{c}	11.15 ± 0.22^{c}
Total FAA	30.45 ± 0.46^{a}	22.66 ± 0.32^{c}	26.88 ± 0.06^{b}	22.40 ± 0.22^{c}	22.48 ± 0.42^{c}

Abbreviation: ΣEAA: total essential amino acids (Thr, Val, Met, Ile, Leu, Phe, Lys, His, Arg); ΣNEAA: total non-essential amino acids (Asp, Glu, Ser, Gly, Ala, Cys, Tyr, Pro); Umami: Asp, Glu; Sweet: Thr, Ala, Ser, Gly, Pro; Bitter: Val, Met, Ile, Leu, Arg, Phe. Different letters in the same peer indicate significant differences between different sterilization methods ($p < 0.05$).

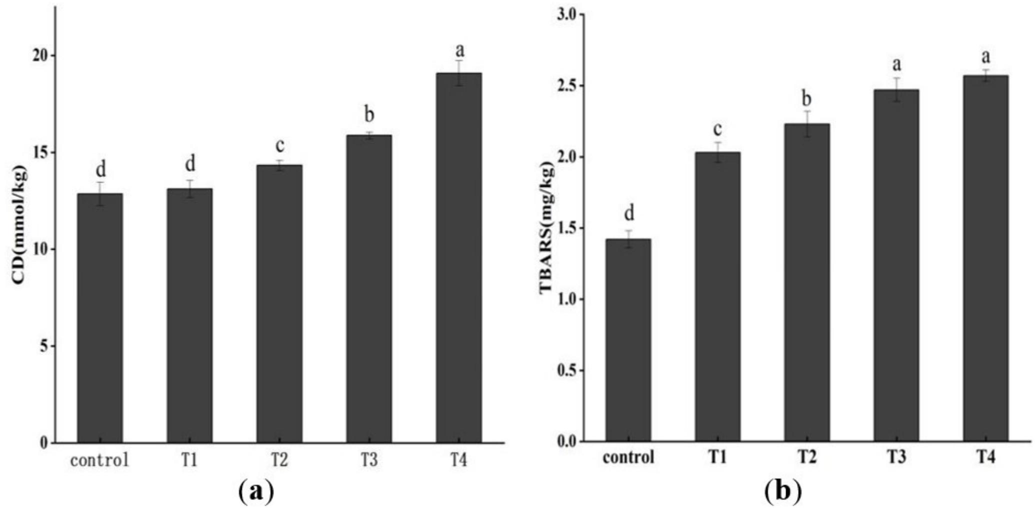

Figure 2. Lipid oxidation analysis: (a) changes in the conjugated diene (CD) of Dezhou braised chicken with different sterilization methods; (b) changes in the TBARS of Dezhou braised chicken with different sterilization methods. Different letters indicate significant differences between different sterilization methods ($p < 0.05$).

reducing sugar (Domínguez et al., 2015). The oxidation in some sensitive amino acids, such as histidine, can be another reason for their reduction (Jannat-Alipour et al., 2010). The thermal decomposition rate of sensitive amino acids generally increases with temperature.

3.5 Lipid oxidation

When evaluating the primary and secondary products of lipid oxidation, CD and TBARS can be employed as markers (Karwowska & Dolatowski, 2017). Figure 2 demonstrates that sterilization temperature and time had a substantial impact on the degree of lipid oxidation (CD and TBARS). There were significant differences in the content of the CD and TBARS values among the five groups ($p < 0.05$). The CD and TBARS values in the control were 12.86 mmol/kg and 1.42 mg/kg, respectively. The results also indicated that sterilization therapy sped up CD synthesis, which promoted the rise in CD concentration. In the T1, T2, T3 and T4 conditions, CD concentration gradually increased, to 13.11 mmol/kg, 14.33 mmol/kg, 15.87 mmol/kg and 19.08 mmol/kg, respectively. All four treated groups, except for T4, were significantly different compared to the control group. Compared to the control group, the TBARS value was significantly increased for the four sterilized conditions. The TBARS value at T3 and T4 (2.47 and 2.57 mg/kg) was significantly higher than T1 and T2 (2.03 and 2.23 mg/kg). By contrast, the TBARS values were significantly different at 50 min for treatment times. The double bonds of hydroperoxides in polyunsaturated fatty acids are rearranged during the initial phases of lipid oxidation, which causes CD production (Qu et al., 2020). In the primary stage of lipid oxidation, high temperatures cause the breakdown of polyunsaturated fatty acids, producing hydroperoxides and other primary oxidation products. Primary autoxidation is then followed by a series of successive secondary reactions, which led to the degradation of hydroperoxides and the formation of a wide range of compounds, including thiobarbituric acid reactive substances (TBARS) and volatile compounds (Roldan et al., 2014). Lipid autooxidation, to a certain extent, produces an off-flavor of rancidity, known as a "warmed-over flavor". However, moderate lipid oxidation during processing contributes to desirable aromas (Song et al., 2011).

4 Conclusion

The results of this study showed that there were significant differences in colour, texture, flavour and CD and TBARS values of Dezhou braised chicken when using the four sterilization treatments. Compared to the control group, the lipid oxidation values (CD and TBARS) were significantly increased, for four sterilization treatments. Compared to T1, T3 and T4, the T2 had the best L^*, a^*, and b^* values, and lower hardness, which provided a more palatable option for older consumers. The E-tongue resulted showed a significant difference in flavour between T2 and the other treated conditions. The free amino acid analysis showed that the loss of free amino acids was minimal, and the retention of taste components was the greatest at T2 condition. Taken together, T2 sterilization might as be a reasonable sterilization condition for Dezhou braised chicken in the future, due to its positive effects on extending shelf life while maintaining sensory and flavour qualities. The results of this study could guide Dezhou braised chicken industry in selecting more appropriate sterilization parameters to improve the quality of their products.

Conflict of interest

The authors declare no conflict of interest.

Availability of data and material

Data are contained within the article.

Funding

This research was funded by National Key R&D Program of China, grant number 2019YFC1605900.

Acknowledgements

The authors thank Shandong Dezhou Braised Chicken Co. for providing the raw materials and for supporting the study.

References

Abdulhameed, A., Yang, T., & Abdulkarim, A. (2016). Kinetic of texture and colour changes in chicken sausage during superheated steam cooking. *Polish Journal of Food and Nutrition Sciences*, 66(3), 199-209. http://dx.doi.org/10.1515/pjfns-2015-0044.

Araújo, C. D. L. D., Silva, G. F. G. D., Almeida, J. L. S. D., Ribeiro, N. L., Pascoal, L. A. F., Silva, F. A. P. D., Ferreira, V. C. D. S., & Martins, T. D. D. (2022). Use of ultrasound and acerola (Malpighia emarginata) residue extract tenderness and lipid oxidation of pork meat. *Food Science and Technology*, 42, e66321. http://dx.doi.org/10.1590/fst.66321.

Arvanitoyannis, I. S., Vasiliki, K., Bouletis, A. D., & Papaloucas, C. (2011). Study of changes in physicochemical and microbiological characteristics of shrimps (Melicertus kerathurus) stored under modified atmosphere packaging. *Anaerobe*, 17(6), 292-294. http://dx.doi.org/10.1016/j.anaerobe.2011.04.006. PMid:21549215.

Bai, S., Wang, Y., Luo, R., Ding, D., Bai, H., & Shen, F. (2021). Characterization of flavor volatile compounds in industrial stir-frying mutton sao zi by GC-MS, E-nose, and physicochemical analysis. *Food Science & Nutrition*, 9(1), 499-513. http://dx.doi.org/10.1002/fsn3.2019. PMid:33473311.

Cho, G., & Ha, J. (2019). Application of X-ray for inactivation of foodborne pathogens in ready-to-eat sliced ham and mechanism of the bactericidal action. *Food Control*, 96, 343-350. http://dx.doi.org/10.1016/j.foodcont.2018.09.034.

Domínguez, R., Borrajo, P., & Lorenzo, J. M. (2015). The effect of cooking methods on nutritional value of foal meat. *Journal of Food Composition and Analysis*, 43, 61-67. http://dx.doi.org/10.1016/j.jfca.2015.04.007.

Duan, Y., Zheng, F., Chen, H., Huang, M., Xie, J., Chen, F., & Sun, B. (2015). Analysis of volatiles in Dezhou braised chicken by comprehensive two-dimensional gas chromatography/high resolution-time of flight mass spectrometry. *Lebensmittel-Wissenschaft + Technologie*, 60(2), 1235-1242. http://dx.doi.org/10.1016/j.lwt.2014.09.006.

Forde, C. G., van Kuijk, N., Thaler, T., Graaf, C., & Martin, N. (2013). Texture and savoury taste influences on food intake in a realistic hot lunch time meal. *Appetite*, 60(1), 180-186. http://dx.doi.org/10.1016/j.appet.2012.10.002. PMid:23085683.

García-Segovia, P., Andrés-Bello, A., & Martínez-Monzó, J. (2007). Effect of cooking method on mechanical properties, color and structure of beef muscle (M. pectoralis). *Journal of Food Engineering*, 80(3), 813-821. http://dx.doi.org/10.1016/j.jfoodeng.2006.07.010.

Gheorghe, A., Hăbeanu, M., Lefter, N. A., Turcu, R. P., Tudorache, M., & Custură, I. (2021). Evaluation of muscle chemical and amino acids composition in broiler chicks fed sorghum or Sorghum-Pea diets. *Brazilian Journal of Poultry Science*, 23(4), eRBCA-2021-1447. http://dx.doi.org/10.1590/1806-9061-2021-1447.

Hasani, E., Csehi, B., Darnay, L., Ladányi, M., Dalmadi, I., & Kenesei, G. (2022). Effect of combination of time and temperature on quality characteristics of sous vide chicken breast. *Foods*, 11(4), 521. http://dx.doi.org/10.3390/foods11040521. PMid:35205995.

Hunt, M. C., Sørheim, O., & Slinde, E. (1999). Color and heat denaturation of myoglobin forms in ground beef. *Journal of Food Science*, 64(5), 847-851. http://dx.doi.org/10.1111/j.1365-2621.1999.tb15925.x.

Jannat-Alipour, H., Shabanpoor, B., Shabani, A., & Mahoonak, A. S. (2010). Effects of cooking methods on physicochemical and nutritional properties of Persian sturgeon Acipenser persicus fillet. *International Aquatic Research*, 2, 15-23.

Jiang, Q., Han, J., Gao, P., Yu, L., Xu, Y., & Xia, W. (2018). Effect of heating temperature and duration on the texture and protein composition of Bighead Carp (Aristichthys nobilis) muscle. *International Journal of Food Properties*, 21(1), 2110-2120. http://dx.doi.org/10.1080/10942912.2018.1489835.

Jiao, X., Shu, Y., Rao, W., Zhang, Z., & Cheng, S. (2022). Effects of lactic acid bacteria and yeast on mutton quality at different temperatures. *Food Science and Technology*, 42, e46122. http://dx.doi.org/10.1590/fst.46122.

Karwowska, M., & Dolatowski, Z. J. (2017). Effect of acid whey and freeze-dried cranberries on lipid oxidation and fatty acid composition of nitrite-/nitrate-free fermented sausage made from deer meat. *Asian-Australasian Journal of Animal Sciences*, 30(1), 85-93. http://dx.doi.org/10.5713/ajas.16.0023. PMid:27165018.

Kurihara, K. (2015). Umami the fifth basic taste: history of studies on receptor mechanisms and role as a food flavor. *BioMed Research International*, 2015, 189402. http://dx.doi.org/10.1155/2015/189402. PMid:26247011.

Lino, L. P. F. D., Pereira, J. M. Fo., Souza, M. P. D., Araújo, D. G. D. S., Oliveira, J. P. F. D., Silva, E. C. D. Fo., Silva, A. L. D., Mazzetto, S. E., Oliveira, R. L., Rocha, K. N. D. S., Moura, J. F. P. D., & Bezerra, L. R. (2022). Control of microbial growth and lipid oxidation on beef steak using a cashew nut shell liquid (CNSL)-based edible coating treatment. *Food Science and Technology*, 42, e06822. http://dx.doi.org/10.1590/fst.06822.

Liu, D., Li, S., Wang, N., Deng, Y., Sha, L., Gai, S., Liu, H., & Xu, X. (2017). Evolution of taste compounds of Dezhou-braised chicken during cooking evaluated by chemical analysis and an electronic tongue system. *Journal of Food Science*, 82(5), 1076-1082. http://dx.doi.org/10.1111/1750-3841.13693. PMid:28407240.

Long, M., Liu, M., Li, Y., Tian, Z., He, Y., Shi, B., Liang, Q., & Tan, S. (2021). Analysis of flavor compounds in marinated chicken wings after irradiation and natural antioxidant (phytic acid and tea polyphenols) treatment. *International Journal of Food Engineering*, 17(10), 783-794. http://dx.doi.org/10.1515/ijfe-2021-0097.

Martens, H., Stabursvik, E., & Martens, M. (1982). Texture and colour changes in meat during cooking related to thermal denaturation of muscle proteins. *Journal of Texture Studies*, 13(3), 291-309. http://dx.doi.org/10.1111/j.1745-4603.1982.tb00885.x.

Nurul, H., Alistair, T. L. J., Lim, H. W., & Noryati, I. (2010). Quality characteristics of malaysian commercial beef frankfurters. *Journal of Agricultural and Food Chemistry*, 17(2), 469-476.

Ortiz, J., Lemus-Mondaca, R., Vega-Gálvez, A., Ah-Hen, K., Puente-Diaz, L., Zura-Bravo, L., & Aubourg, S. (2013). Influence of air-drying temperature on drying kinetics, colour, firmness and biochemical characteristics of Atlantic salmon (Salmo salar L.) fillets. *Food Chemistry*, 139(1-4), 162-169. http://dx.doi.org/10.1016/j.foodchem.2013.01.037. PMid:23561093.

Panseri, S., Martino, P. A., Cagnardi, P., Celano, G., Tedesco, D., Castrica, M., Balzaretti, C., & Chiesa, L. M. (2018). Feasibility of biodegradable based packaging used for red meat storage during shelf-life: a pilot study. *Food Chemistry*, 249, 22-29. http://dx.doi.org/10.1016/j.foodchem.2017.12.067. PMid:29407927.

Pulgar, J. S., Gázquez, A., & Ruiz-Carrascal, J. (2012). Physicochemical, textural and structural characteristics of sous-vide cooked pork cheeks as affected by vacuum, cooking temperature, and cooking time. *Meat Science*, 90(3), 828-835. http://dx.doi.org/10.1016/j.meatsci.2011.11.024. PMid:22154568.

Putnik, P., Kresoja, Ž., Bosiljkov, T., Jambrak, A. R., Barba, F. J., Lorenzo, J. M., Roohinejad, S., Granato, D., Žuntar, I., & Kovačević, D. B. (2019). Comparing the effects of thermal and non-thermal technologies on pomegranate juice quality: a review. *Food Chemistry*, 279, 150-161. http://dx.doi.org/10.1016/j.foodchem.2018.11.131. PMid:30611474.

Qu, C., He, Z., Wang, Z., Li, S., Wang, Z., & Li, H. (2020). Effects of NaCl content and drying temperature on lipid oxidation, protein oxidation, and physical properties of dry-cured chicken. *Journal of Food Science*, 85(6), 1651-1660. http://dx.doi.org/10.1111/1750-3841.15129. PMid:32460413.

Roldan, M., Antequera, T., Armenteros, M., & Ruiz, J. (2014). Effect of different temperature–time combinations on lipid and protein oxidation of sous-vide cooked lamb loins. *Food Chemistry*, 149, 129-136. http://dx.doi.org/10.1016/j.foodchem.2013.10.079. PMid:24295686.

Rolls, E. T. (2009). Functional neuroimaging of umami taste: what makes umami pleasant? *The American Journal of Clinical Nutrition*, 90(3), 804S-813S. http://dx.doi.org/10.3945/ajcn.2009.27462R. PMid:19571217.

Sforza, S., Galaverna, G., Schivazappa, C., Marchelli, R., Dossena, A., & Virgili, R. (2006). Effect of extended aging of parma dry-cured ham on the content of oligopeptides and free amino acids. *Journal of Agricultural and Food Chemistry*, 54(25), 9422-9429. http://dx.doi.org/10.1021/jf061312+. PMid:17147428.

Song, S., Zhang, X., Hayat, K., Liu, P., Jia, C., Xia, S., Xiao, Z., Tian, H., & Niu, Y. (2011). Formation of the beef flavour precursors and their correlation with chemical parameters during the controlled thermal oxidation of tallow. *Food Chemistry*, 124(1), 203-209. http://dx.doi.org/10.1016/j.foodchem.2010.06.010.

Tan, F., Zhan, P., Zhang, Y., Yu, B., Tian, H., & Wang, P. (2022). Development stage prediction of flat peach by SVR model based on changes in characteristic taste attributes. *Food Science and Technology*, 42, e18022. http://dx.doi.org/10.1590/fst.18022.

Van Laack, R. L. J. M., Berry, B. W., & Solomon, M. B. (1996). Variations in internal color of cooked beef patties. *Journal of Food Science*, 61(2), 410-414. http://dx.doi.org/10.1111/j.1365-2621.1996.tb14205.x.

Wang, Q., Zhang, M., Adhikari, B., Cao, P., & Yang, C. H. (2019). Effects of various thermal processing methods on the shelf-life and product quality of vacuum-packaged braised beef. *Journal of Food Process Engineering*, 42(4), e13035. http://dx.doi.org/10.1111/jfpe.13035.

Wang, T., Zhao, L., Sun, Y., Ren, F., Chen, S., Zhang, H., & Guo, H. (2016). Changes in the microbiota of lamb packaged in a vacuum and in modified atmospheres during chilled storage analysed by high-throughput sequencing. *Meat Science*, 121, 253-260. http://dx.doi.org/10.1016/j.meatsci.2016.06.021. PMid:27376249.

Wang, Z., Tu, J., Zhou, H., Lu, A., & Xu, B. (2020). A comprehensive insight into the effects of microbial spoilage, myoglobin autoxidation, lipid oxidation, and protein oxidation on the discoloration of rabbit meat during retail display. *Meat Science*, 172, 108359. http://dx.doi.org/10.1016/j.meatsci.2020.108359. PMid:33160212.

Xia, X., Kong, B., Liu, Q., & Liu, J. (2009). Physicochemical change and protein oxidation in porcine longissimus dorsi as influenced by different freeze-thaw cycles. *Meat Science*, 83(2), 239-245. http://dx.doi.org/10.1016/j.meatsci.2009.05.003. PMid:20416749.

Xu, J., Zhang, M., Bhandari, B., & Cao, P. (2018). Microorganism control and product quality improvement of twice-cooked pork dish using ZnO nanoparticles combined radio frequency pasteurization. *LWT*, 95, 65-71. http://dx.doi.org/10.1016/j.lwt.2018.04.067.

Yao, W., Cai, Y., Liu, D., Chen, Y., Li, J., Zhang, M., Chen, N., & Zhang, H. (2022). Analysis of flavor formation during production of Dezhou braised chicken using headspace-gas chromatographyion mobility spectrometry (HS-GC-IMS). *Food Chemistry*, 370, 130989. http://dx.doi.org/10.1016/j.foodchem.2021.130989. PMid:34509944.

Zhu, C., Tian, W., Sun, L., Liu, Y., Li, M., & Zhao, G. (2019). Characterization of protein changes and development of flavor components induced by thermal modulation during the cooking of chicken meat. *Journal of Food Processing and Preservation*, 43(7), e13949. http://dx.doi.org/10.1111/jfpp.13949.

Zoldan, S. M., Braga, G. D. S., Fonseca, F. J., & Carrão-Panizzi, M. C. (2014). Electronic tongue system to evaluate flavor of soybean (Glycine Max (L.) Merrill) genotypes. *Brazilian Archives of Biology and Technology*, 57(5), 797-802. http://dx.doi.org/10.1590/S1516-8913201402176.

Supplementary Material

Supplementary material accompanies this paper.

Table S1. Limit of detection (LOD) and limit of quantification (LOQ) for free amino acid analytical methods.

This material is available as part of the online article from https://doi.org/10.1590/fst.119222