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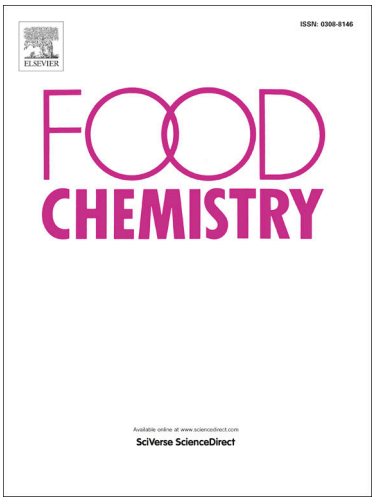

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PII: S0308-8146(23)00792-6
DOI: https://doi.org/10.1016/j.foodchem.2023.136174
Reference: FOCH 136174

To appear in: *Food Chemistry*

Received Date: 3 January 2023
Revised Date: 10 March 2023
Accepted Date: 13 April 2023

Please cite this article as: Huang, X., You, Y., Liu, Q., Dong, H., Bai, W., Lan, B., Wu, J., Effect of gamma irradiation treatment on microstructure, water mobility, flavor, sensory and quality properties of smoked chicken breast, *Food Chemistry* (2023), doi: https://doi.org/10.1016/j.foodchem.2023.136174

Effect of gamma irradiation treatment on microstructure, water mobility, flavor, sensory and quality properties of smoked chicken breast

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Abstract

Effect of gamma irradiation on quality, flavor and sensory properties of smoked chicken breasts were investigated. Results indicated irradiation doses > 3 kGy were effective for sterilization, while also produced a significant effect on overall quality of smoked chicken breast. Irradiation treatment could inhibit protein oxidation and accelerate lipid oxidation of smoked chicken breasts. High irradiation doses could increase the instability of free and bound water, as well as increase muscle fiber gap and juice loss significantly. Irradiation treatment also promoted free fatty acids and taste-presenting nucleotides degradation, effectively increased fresh-tasting amino acids contents and decreased bitter and sweet-tasting amino acids contents. The types and relative contents of volatiles, especially aldehydes, alcohols, aromatic hydrocarbons, and phenolic compounds, also changed after irradiation, while tartaric, pyruvic, and malic acids decreased. Results obtained can provide valuable reference data for improving the quality and flavor of smoked chicken breasts using gamma irradiation technology.

Keywords: Gamma irradiation; smoked chicken breast; water mobility; flavor; lipid oxidation

1. Introduction

There has been a growing demand for meat products with high nutritional value, convenience, and unique flavors (Chiesa et al., 2022). As one of the famous meat products in China, smoked chicken breast has the characteristics of low fat, high protein, firm muscle fibers, and tender texture. At the same time, it is widely spread all over the world for its unique taste and flavor (Zhang, Xia, Sun, Liu & Chen, 2022). Even though the smoking process provides some preservative abilities in chicken breasts, smoked chicken breasts with high nutritional value and moisture content remain susceptible to microbial contamination (Wang, Chen, Xu, Sun, Liu & Kong, 2022). The presence of numerous microorganisms in meat products not only reduces their shelf life but also significantly affects their quality and flavor, resulting in substantial losses to the industry (Wei, Liu, Zhao, Li & Zhang, 2022). The traditional meat preservation methods (heating, refrigeration, and high-temperature treatment) have greater impacts on the quality and nutrient content of meat, such as oxidation of lipids and proteins, protein denaturation, moisture loss, color deterioration, flavor loss, texture changes, and microbial spoilage (Wei et al., 2022; Xu et al., 2021).

Low-temperature sterilization technology can effectively inhibit microorganisms in food to make it safe and maintain its quality. With irradiation, meat is tenderized, shelf life is extended, pathogens are destroyed, and spoilage microorganisms are killed. Thus, irradiation is considered a safe and effective method of keeping meat fresh (Zhang et al., 2020). Gamma irradiation can destroy the chemical bonds of microbial DNA and macromolecules such as proteins and lipids, and combine with food ingredients to produce physical, chemical, and biological effects, killing the surface and interior of the food. Parasites and pathogenic bacteria, maintain their quality to the maximum extent and prolong the shelf life of food (Rodrigues et al., 2020). Several studies have shown that irradiation could kill or inhibit the total number of microorganisms in meat products, and even kill viruses, with no significant effect on the overall quality characteristics of meat during frozen storage (Cordeiro, Mouro, Dos Santos & Wagner, 2022).

However, some studies have shown that due to the different structures and composition of different meat products, different irradiation doses can change the redox potential of the meat system, thus accelerating the oxidation of fats and proteins, resulting in changes in the color, taste, and flavor of the meat (Jia, Wang, Zhang, Shi & Shi, 2022). It has been reported that irradiation sterilization increased the contents of fresh and tasteless amino acids, while reduced the contents of bitter amino acids and organic acids, thus improving the overall taste of pork ribs (Sun, Zhang, Zhang, Zhang & Sun, 2021). In another study, irradiation doses of 3 kGy did not affect yak meat quality, while irradiation doses of 5 kGy resulted in poorer yak meat quality and significant irradiation off-flavors (Wang et al., 2022). Previous work also found irradiation at 9 kGy combined with aging could improve beef tenderness, but also led to discoloration (Rodrigues et al., 2020). However, to the best of our

knowledge, different gamma irradiation doses on the quality and flavor characteristics of smoked chicken breasts were rare reported.

It has become a general trend in the meat industry to choose the right irradiation dose for different meat products. Therefore, the aim of the present study was to investigate the effects of different gamma irradiation doses on the microstructure, water mobility, flavor, sensory and quality properties of smoked chicken breast. It was the first report of the systematic analysis of physicochemical properties of smoked chicken breast treated by gamma irradiation, especially microstructure, water mobility, flavor and sensory characteristics. Results obtained in this work could provide reference and technical support to ensure the quality of smoked chicken breast on the basis of the effective extension of its shelf life, and also provide theoretical basis for the application of irradiation in meat products.

2. Materials and methods

2.1. Chemicals and reagents

Amino acid mixture standard solutions AN-II and B (chromatographic grade, containing 17 protein amino acids, purity 99.0%) were purchased from Wako Pure Pharmaceutical Co. Ltd (Tokyo, Japan). The standards of 37 fatty acid methyl esters (purity 99.0%) were obtained from Sigma-Aldrich (Shanghai, China). Adenosine-5′-triphosphate (ATP), adenosine-5′-diphosphate (ADP), adenosine-5′-monophosphate (AMP), inosine-5′-monophosphate (IMP), guanosine-5′-monophosphate (GMP), inosine (HxR) and hypoxanthine (Hx) (purity ≥ 95%, HPLC) were purchased from Shanghai Genye Biological Reagent Co., (Shanghai, China). Oxalic acid, tartaric acid, pyruvic acid, malic acid, lactic acid, acetic acid, citric acid, and succinic acid (purity ≥95%) were purchased from McLean ltd. (Cameron, USA). Methanol (chromatographically pure), 2-thiobarbituric acid, 1,1,3,3-Tetraethoxypropane, chloroform, absolute ethanol, trichloroacetic acid, sulfosalicylic acid, magnesium chloride (analytically pure) were purchased from Tianjin Yongda Chemical Reagent Co., Ltd. (Tianjin, China).

2.2. Sample and irradiation treatment

Smoked chicken breasts (500 g, per vacuum pack) were provided by the Guangzhou Restaurant Group Co., Ltd (Guangzhou, China). Irradiation treatment was performed at the ^{60}Co gamma irradiation device [a fixed source room wet storage source gamma irradiation device, the model is Q(H) type] in the Guangzhou Radian High Energy Technology Co., Ltd. (Guangzhou, China). The samples were treated at irradiation doses of 2, 3, 4, and 6 kGy, respectively. Indicators were immediately tested after irradiation.

2.3. Microbial analysis

Microbial analysis was performed according to a previous literature (Dai, Han, Li, Gu, Xiao & Lu, 2022).

2.4. Texture and morphological analysis

The texture of samples was analyzed according to the method of a reported paper with several modifications (Cordeiro et al., 2022). Samples were prepared to 4cm in length, 4cm in width, and 3cm in thickness for texture analysis using a Rapid TA Texture Analyzer (Shanghai Tengba Instrument Technology Co., Ltd., Shanghai, China) equipped with a P/36R flat-bottom cylinder probe. The measurement parameters were as follows: TPA full texture mode, test speed of 2 mm/s, probe speed of 3 mm/s, measuring time of 5 s, trigger force of 5 N and compression distance of 30%.

Muscle fiber morphological changes were analyzed using the HE staining method described in a reported literature (Chen et al., 2021). Briefly, samples were cut into 1 cm × 1 cm × 1 cm size and fixed in 4% paraformaldehyde tissue fixative for over 24 h. After trimming, samples were dehydrated in a series of ethanol gradients (75%, 85%, 90%, 95%, and anhydrous ethanol), embedded in paraffin, trimmed again, and flattened. The sections were then preserved, scanned, and photographed, and the images were acquired and analyzed using Case Viewer 2.0 software (China).

2.5. Determination of color and pH

The lightness (L*), redness (a*) and yellowness (b*) were determined using a Weifu photoelectric colorimeter (Weifu Optoelectronics Technology Co., Ltd., Shenzhen, China). The pH was measured with a calibrated pH meter. Briefly, 5 g of the crushed sample was weighed and put into a conical flask. Distilled water of 75 mL was added and the sample solution was stirred evenly. After placing for 30 min, the solution was centrifuged and the supernatant was obtained for pH measurement.

2.6. LF-NMR spectroscopy

The LF-NMR measurements were conducted according to the method described in a previous literature (Ye et al., 2022). Briefly, after equilibrating at room temperature for 30 minutes, the samples were cut into cuboids of 3×1×2 cm^3 and placed in NMR tubes (model MesoMR23-060H-1, Low-field NMR imaging analyzer, Suzhou Niumai Instrument Analysis Co., Ltd. China). A Carr–Purcell–Meiboom–Gill pulse sequence was used to measure the spin-spin relaxation time (T_2). Other parameters were SW = 100 kHz, SF = 21 MHz, RFD = 0.002 ms, RG1 = 20.0 dB, P1 = 10.0 s, DRG1 = 2, TD = 1024, PRG = 1, TW = 4000 ms, and NS = 2.

2.7. Determination of drip loss

The mass of the complete packaging samples after irradiation treatments was first weighed (m_0). Then, the packaging bag was opened and the juice in the packaging

bag was poured out. The residual juice on the surface of the chicken breast was dried and the total mass of the packaging bag and chicken breast (m_1) was weighed. Bags were individually weighed (m_2). The drip loss was calculated according to the following formula.

$$drip\ loss = \frac{m_2 - m_0}{m_1 - m_0} \times 100\%$$

2.8. Lipid and protein oxidation analysis

The thiobarbituric acid reactive substances (TBARs) and total volatile basic nitrogen (TVB-N) were measured according to the method of (Chen, Luo, Lou, Wang, Yang & Shen, 2021), and report of (Li, Tang, Shen & Dong, 2019), respectively.

2.9. Fatty acid measurement

Fatty acid measurement was according to the method reported in a literature (Feng, Tjia, Zhou, Liu, Fu & Yang, 2020).

2.10. Sensory analysis

The sensory evaluation of smoked chicken breast was referred to a reported literature (Zhang, Chen, Liu, Xia, Wang & Kong, 2022) with slight modifications. The effect of irradiation treatment on the sensory properties of smoked chicken breasts was evaluated by a trained ten-member panel (between 20 and 25 years of age with 10 females and 10 males). Smoked chicken breasts were randomly placed in trays coded with randomly arranged three-digit numbers for evaluation by the sensory panel. The results of the sensory evaluation were recorded using a 25-point scale: color (1: dull, 25: bright color), odor (1: no special smoked meat flavor, heavy sourness, 25: strong smoky flavor, strong meatiness), histomorphology (1: rotten and moldy meat with the sticky surface, 25: firm and elastic, tight and firm structure, flat cut surface), and taste (1: no umami 25: good umami). A comprehensive evaluation of the overall acceptability of the samples was performed.

2.11. Analysis of volatiles

The volatile compounds were analyzed according to the method reported in a previous literature (Jo, An, Arshad & Kwon, 2018). The 2,4,6-trimethylpyridine (10 uL, 7.50 mol/mL) was used as the internal standard. The sample (3.0±0.1g) was placed in a 20 ml vial with headspace and a 50/30 m of DVB-PDMS (Supelcog Co., Ltd. USA) in the vial. The headspace vial containing the sample was fixed on the extraction table and equilibrated for 10 minutes, and the extraction head was inserted into the vial and heated at 50°C for 50 minutes. Next, the fiber was injected into the port of a GC-MS system (8890-5977B, Agilent Technologies Co., Ltd. USA), and retained for thermal desorption at 250°C for 5 min. Gas chromatography conditions:

Gas chromatography conditions: DB-5MS gas chromatography column (30 × 0.25 μm × 0.25 μm, Agilent Technologies, USA), with helium as the carrier gas (99.999%). The flow rate was 1 mL/min, with an injection volume of 1 μL. Temperature ramps were performed at 3 degrees Celsius per minute to 70 degrees Celsius and held for 3 min, 6 degrees Celsius per minute to 140 degrees Celsius, and 8 degrees Celsius per minute to 230 degrees Celsius over 2 min. Qualitative and quantitative analysis was performed by comparing the retention times of volatile compounds with the NIST17.L library using Agilent GC-MSD software. The concentration of the volatile compounds was calculated by comparing the peak areas of volatiles with those of the internal standards at known concentrations. The Odor Activity Values (OAVs) were calculated according to a previous literature (Zhang, Hu, Wang, Kong & Chen, 2021).

2.12. Taste analysis

The free amino acid content was determined according to a previous paper (Jo et al., 2018) by using a fully automatic amino acid analyzer (Hitachi Automatic Biochemical Analyzer Instrument Co., Ltd., Japan). Nucleotide contents were analyzed according to the method in a reported paper (Zhang, Zhang, Wang, Xing & Zhang, 2020). Organic acids were measured according to the method described by (Hu, Li, Zhu, Kong, Liu & Chen, 2021).

2.13. Statistical analyses

All experiments were performed as mean ± SD of three or five independent experiments (n = 3 or 5), and the results were analyzed using SPSS Statistics 22.0 (software v.10.0.2, Minnesota, USA). OriginPro 2021(Origin Lab, Northampton, MA), Prism 8.0 (GraphPad Software, USA), and Tbtools (China) were used for plotting. Pearson correlation was applied to analyze the relationship between sensory and physical and chemical indicators of smoked chicken breast.

3. Results and discussion

3.1. Microbiological changes in irradiated smoked chicken breast

The aerobic plate count results of the irradiated smoked chicken breast are presented in Table 1. As shown in Table 1, the initial aerobic plate count at control was 2.89 lgCFU/g. The aerobic plate count in smoked chicken breasts decreased significantly ($P<0.05$) with the increase of ^{60}Co gamma irradiation dose, and the total number of colonies was 0 lgCFU/g when the irradiation dose was 6 kGy. At the beginning of storage, the coliform counts of the samples were below the detectable values (Table 1). Irradiation treatment can effectively inhibit the reproduction and growth of sample microorganisms. This result was in agreement with a reported work in which authors found that irradiation successfully improved the microbial quality of frozen duck meats samples (Li et al., 2022).

3.2. Texture and microstructure changes of irradiated smoked chicken breast

The effect of irradiation on the hardness, springiness, and springiness of all samples is shown in Table 1. Hardness measures a meat's maturation level since it is affected by the denaturation of proteolysis of meat proteins and water loss (Cordeiro et al., 2022). There was an increase in the hardness and chewiness of the irradiated samples with an increase in the irradiation dose ($P<0.05$), but there was a decrease in springiness, which may affect the taste of the samples. Irradiation treatment can denature the protein of smoked chicken breast, or degrade the meat protein and promoted sarcomere elongation through actin and myosin degradation, resulting in decrease of meat quality and loss of springiness (Cordeiro et al., 2022; Rodrigues et al., 2020). The quality characteristics of muscle are related to its microstructure and muscle fiber space is the space formed by the separation of muscle fiber (Zou et al., 2022). To illustrate the effect of irradiation on the change of smoked chicken breast muscle fibers, morphological HE staining scans of vertical muscle fiber sections were performed on smoked chicken breasts (Fig. 1A). Although the muscle fibers gaps of control samples were small, they were generally parallel, tiger myofiber structure with a clear and the diameter of the muscle fibers has little difference. When the irradiation dose was ≥4 kGy, the interfascicular space changed significantly ($P<0.05$). The muscle fiber gap of all samples increased, and the muscle fiber in the irradiated groups increased significantly compared with the control samples ($P<0.05$), while the muscle fiber diameter had no significant ($P>0.05$) change. This may be due to the increase in irradiation dose, the collapse of muscle fibers led to the increase of intercellular enlargement of smoked chicken breast muscle fibers, or the increase of the degree of damage to the protein skeleton structure, the myofibril bundles became loose, and the gaps between the muscle bundles became larger (Zou et al., 2022). Thus, we could see that when the irradiation dose was ≥4 kGy, there is less change in the texture and microstructure of the smoked chicken breasts.

3.3. Color and pH changes of irradiated smoked chicken breast

More than any other sensorial attribute, the color of smoked chicken breasts is one of the most important physical indicators as its influences consumers' willingness to purchase it. Table 1 demonstrates the color of all samples. The L* value in the control samples was nearly 50.00, but it was significantly decreased in the 4 and 6 kGy irradiated samples ($P<0.05$). As the muscle loses water, the surface refractive index decreases, thereby decreasing the L* value, while the b* values showed an increasing trend and the a* value did not change regularly. Therefore, it has a certain influence on the color of the sample when the irradiation dose is >3 kGy. This is in agreement with (Sales et al., 2020) who reported that high doses of irradiation could cause the beef to turn red. The pH affects protein stability, meat color, drip loss, and meat texture. As shown in Table 1, the pH values of the 4 kGy and 6 kGy irradiation groups were lower than those of the control samples ($P < 0.05$), which decreased by

0.13 and 0.06, respectively. Compared with the control sample, the pH value of 2 kGy did not change significantly, but the pH value of 3 kGy increased significantly by 0.07. The pH values of all samples mainly fluctuated around 6.00 as shown in Table 1, and irradiation treatment had no significant ($P<0.05$) effect on the pH values.

3.4. Drip loss changes and LF-NMR analysis of irradiated smoked chicken breast

The distribution and migration of water content in meat have a direct effect on the final overall quality. Proper water status can greatly influence the taste, texture, and overall appeal of meat. The effects of irradiation on the drip loss of smoked chicken breasts are shown in Table 1. With the doses of irradiation increased, the drip loss of smoked chicken breasts significantly increased ($P<0.05$). Compared with the 0 kGy, the 2 kGy dose showed no significant increase in the drip loss of smoked chicken. The drip losses of smoked chicken breasts were significantly ($P<0.05$) increased when the irradiation doses increased to 3, 4, and 6 kGy. Notably, the drip loss of smoked chicken breast irradiated with 6 kGy dose had 1.01% increase in comparison with the control group. It has been reported that protein denaturation would reduce meat's water-holding capacity by increasing muscle fiber diameter (Rodrigues et al., 2020). Another work reported that the modification or denaturation of proteins occurs due to changes in solute concentration within the muscle fiber, resulting in a higher amount of drip loss (Sales et al., 2020).

The transverse relaxation time T_2 in the LF-NMR results can reflect water mobility and distribution of smoked chicken breasts (Fig. 1B). There were four characteristic peaks in the smoked chicken breast's T_2 relaxation time distribution, including T_{21a}, T_{21b}, T_{22}, and T_{23}. Exhibit relatively short relaxation times and are considered bound water - T_{21a} (0-1 ms) and T_{21b} (1-10 ms). Water retained by the microstructure and submicron structure of tissues and membranes is referred to as non-mobile water - T_{22} (10-200 ms). Chicken breasts contain approximately 90% immobile water, which directly affects their ability to retain water (Zhao, Chen, Wongmaneepratip, He, Zhao & Yang, 2021). The timing and relative amounts of peaks reflect the level of water binding and tissue tightness (Li et al., 2022). Table 2 is supplemented with data for T_2, segmental relaxation times (T_{21a}, T_{21b}, T_{22}, T_{23}) and corresponding proportions (P_{21a}, P_{21b}, P_{22}, P_{23}). The relative contents of bound water, non-mobile water, and free water are represented by P_{21}, P_{22}, and P_{23}, respectively, in smoked chicken breasts. The effect of irradiation on the moisture of smoked chicken breast was mainly reflected in the relaxation time of the moisture and did not affect its moisture distribution. As a result of the irradiation treatment, the relaxation times of T_{21a}, T_{21b}, and T_{22} of the irradiated group were significantly shorter than those of the non-irradiated group ($P < 0.05$), indicating that irradiation caused the bound and non-flowing water to be more unstable. Additionally, the relaxation time of T_{23} in smoked chicken breasts increased significantly ($P < 0.05$) as the irradiation dose increased, suggesting that irradiation accelerated the fluidity of free water. Different

processing techniques could lead to changes in the ratio of bound water and free water in meat products, which was closely related to changes in muscle fiber bundle structure, taste, and flavor (Liang, Lin, Chen & Sun, 2022). Compared with 0 kGy, the percentage of the T_{21} peak area was essentially unchanged, the percentage of the T_{23} peak area increased and the percentage of the T_{22} peak area decreased in the irradiated group. On one hand, gamma radiation can ionize and activate the water, causing it to split into free radicals, ions, and hydrogen peroxide radicals, which can interact with components in food (Jia et al., 2022). On the other hand, changes in protein structure and muscle fiber density can increase water fluidity in meat, enlarge the space between muscle fiber structures, and reduce its ability to retain water (Zou et al., 2022).

3.5. TVB-N and TBARS changes in irradiated smoked chicken breast

Proteins in meat products decompose into alkaline nitrogenous compounds, such as ammonia and amines, under the action of endogenous enzymes or extracellular enzymes secreted by microorganisms. A biomarker for protein and amine degradation, Total volatile basic nitrogen (TVB-N) is one of the most useful indicators for evaluating meat quality (Li et al., 2019). In meat products, TVB-N content higher than 15 mg/100 g was considered to be spoiled meat products (Chinese National Standard GB 2707-2016). The TVB-N concentration of the 2 kGy was 9.61 mg/100g, which was not significantly different from the control sample Table 1. However, the TVB-N concentrations were 8.91, 8.44, and 8.68 mg/100g, respectively in 3, 4 and 6 kGy groups, which decreased by 0.47, 1.17, and 0.23 mg/100g respectively, in comparison with the control group. Irradiation could inhibit the increase of TVB-N, and the reason may be due to the inhibition of microbial counts and enzyme activity caused by irradiation (Li et al., 2019; Li et al., 2022). The analysis of TBARS is mainly used to determine the content of malondialdehyde (MDA), which is a main secondary product of lipid oxidation and is considered to be the major marker of lipid-oxidation (Chen, Luo, Lou, Wang, Yang & Shen, 2021). As depicted in Table 1, the initial TBARS values of irradiated samples were increased with irradiation doses, from 0.096±0.00 mg/kg of a control sample to 0.123±0.02 mg/kg, 0.159±0.05 mg/kg, 0.182±0.03 mg/kg, 0.240±0.04 mg/kg of 2 kGy, 3 kGy, 4 kGy, and 6 kGy irradiation groups, respectively ($P < 0.05$), and it increased to approximately 0.03-0.14 mg/kg after gamma irradiation. Considering there was a large amount of water in the meat, ionizing radiation raises hydroxyl radicals in the water system and accelerates oxidative changes in the meat, which have dose-dependent effects (Derakhshan et al., 2018).

3.6. Fatty acid changes in the irradiated smoked chicken breast

Quality characteristics of meat are greatly influenced by its fatty acid (FA) composition, such as flavor, texture, and aromatic taste profile. When FA is exposed to irradiation, its double bond structure can be disrupted, resulting in less detectable

oxidized or free fatty acids (FAAs). FAA reflects some extent the extent of lipid oxidative breakdown in meat (Wu, Xiao, Yin, Zhang & Richards, 2021). The contents and composition of FAAs in non-irradiated and irradiated groups are shown in Figs 1C and 1D. A total of 29 fatty acids were detected in smoked chicken breasts, including 15 saturated fatty acids (SFA), 8 monounsaturated fatty acids (MUFA), and 6 polyunsaturated fatty acids (PUFA). The main FAAs were methyl tridecanoate (C13:0, 31-73% of ∑FAA), methyl oleate (C18:1n9c, 9-26% of ∑FAA), palmitic acid (C16:0, 7-16% of ∑FAA), and linoleic acid (C18:2n6c, 5-15% of ∑FAA). In many meat samples, C16:0 and C18:2n6c were consistently high. C16:0 and C18:2n6c are usually considered important precursor compounds for the flavor of the meat. C18:2N6C can be oxidized by enzymes or undergo automatic oxidation reactions to produce various hydrogen peroxides, which eventually break down into aldehyde compounds. C16:0 can break down into ketones and aromatic compounds (Al-Dalali, Li & Xu, 2022). These compounds are thought to play important roles in the aroma and flavor of the meat. The total free fatty acid content (∑FAA) and individual fatty acid content in the irradiated groups were significantly different ($P<0.05$) in comparison with the 0 kGy group. The 2, 3, 4, and 6 kGy groups decreased by 162.64 mg/g, 78.04 mg/g, 18.95 mg/g, and 161.77 mg/g respectively, and the most obvious ones were 2 kGy and 6 kGy. This may be due to oxidative processes that occur in unsaturated fatty acids when they are exposed to ionizing radiation, which can generate highly reactive free radicals that replace the carbon-bonded hydrogen atoms near the double bonds (Jia, Wang, Zhang, Shi & Shi, 2022). As the irradiation dose increased, the proportion of SFA in total fatty acids significantly increased, while that of MUFA and PUFA in total fatty acids significantly decreased. SFA change was mainly reflected in the reduction and increase of C13:0 and C16:0. MUFA change was mainly reflected in the reduction of C18:1n9c. PUFA change was mainly reflected in the decrease of C18:2n6c. In general, the oxidation of SFA has been found to negatively affect the aroma of food, whereas the oxidation of MUFA and PUFA can produce various aroma components. From this, it was speculated that C13:0 as an SFA may be related to the formation of off-flavor in high-dose irradiated smoked chicken breast, and the degradation of C18:2n6 as a MUFA and C18:2n6c as a PUFA may be related to the positive aroma odor of smoked chicken breast. (Kunyaboon, Thumanu, Park, Khongla & Yongsawatdigul, 2021) silver carp C13:0 levels increased with increased irradiation dose, while the content of C18:1n9c and C18:2n6c decreased significantly, nonanal and 1-octanol may be derived from C18:2n6c and C18:1n9c oxidative degradation. It has been reported that irradiation treatment could lead to a significant decrease in the ratio of oleic acid (C18:1), linoleic acid (C18:2), and arachidonic acid (C20:4n6) in largemouth bass meat, which may be attributed to their C=C bond being the most unstable during the irradiation process (Huang et al., 2022).

3.7. Sensory evaluation of irradiated smoked chicken breast

The highest sensory evaluation of samples was the 0 kGy group, which was

95±0.01 points, as shown in Fig 2A. The smoked chicken breasts had a shiny appearance, a strong smoky flavor, a firm and elastic texture, and a delicious taste. However, the sensory score of smoked chicken breasts decreased gradually with the increase of irradiation dose. Sensory evaluation indicated that irradiation treatment at 2 kGy did not significantly affect ($P > 0.05$) the sensory attributes of smoked chicken breasts, while the irradiated smoked chicken breasts at 3, 4, and 6 kGy presented decreases in the sensory attributes. Although sensory indicators changed significantly in the 3, 4, and 6 kGy, the overall acceptability of these groups was within a reasonable range. Correlation analysis of sensory evaluation and physical and chemical indicators including TVC, pH, TBARS, TVB-N, drip loss, texture, color and HE changes of smoked chicken breasts is presented in Fig. 2B. Results clearly showed the correlation between the sensory and the individual metrics. Sensory and TBARS, TVB-N, and drip loss had a very significant correlation($P \leq 0.01$). The irradiation dose was positively correlated with the content of TBARS, and the drip loss had a close relationship with the texture, which may be an important reason for affecting the sensory score. Irradiation was found to have a positive correlation with the TBARS content. Higher levels of lipid oxidation could result in the production of more flavor and taste compounds, which could ultimately impact the sensory evaluation scores for flavor and taste. Additionally, the drip loss rate was closely related to the texture of the meat and maybe a key factor affecting the sensory evaluation scores for texture.

3.8. Flavor changes in irradiated smoked chicken breast

Table 3 shows the volatiles results of smoked chicken breasts after irradiation treatment. A total of 64 volatiles were identified in the smoked chicken breast, including aldehydes (8), alcohols (7), aromatic hydrocarbons (6), phenols (7), esters (9), terpenes (15), ketones (4), amines (3), sulfide (1), acids (2), others compounds (2). A total of 28, 25, 25, 15, and 26 compounds were found in the 0, 2, 3, 4, and 6 kGy groups, and the relative contents were 239.32, 106.12, 214.03, 265.25, 324.14 mg/kg, respectively. The type and content of volatiles in smoked chicken breasts were significantly affected by irradiation. There are abundant amounts of water, fats, proteins, and other compounds in smoked chicken breasts. In the presence of irradiation, the water fraction can be broken down into hydroxyl radicals (oxidizing radicals) and aqueous electrons and hydrogen atoms (reducing compounds). When oxygen is present, these compounds initiate various oxidation reactions of organic molecules, changing the flavor of the meat (Bliznyuk et al., 2022).

Four aldehydes were detected in the 0 kGy group, including hexanal, nonanal, 8-Octadecenal, and heptanal. Under the action of oxidation and complex enzyme systems, these aldehydes can be degraded into straight-chain aldehydes such as nonanal and hexanal (Jia, Wang, Zhang, Shi & Shi, 2022). Aldehydes with a low odor threshold value are crucial in creating the distinctive flavor profile of smoked chicken breasts, contributing to their clear, fruity, fatty, and nutty aroma. After irradiation

treatment, the content of hexanal and nonanal increased, especially in 3 kGy and 6 kGy. Octanal, decanal, and 5-ethylcyclopent-1-enecarboxaldehyde were only detected in the irradiated group, and the OAVs of octanal and decanal was greater than 1 and played an important role in overall flavor of smoked chicken breast. The general flavor profile of decanal is greasy, citrusy, peachy, and floral, while octanal is citrusy. High concentrations of hexanal and octanal had been considered a sign of lipid oxidation, one of the main causes of meat off-flavors in other reports (Cordeiro et al., 2022). High concentrations of nonanal and octanal give off carrion and a pungent odor. This may be one of the reasons why smoked chicken breasts exposed to high doses of irradiation emit an "irradiated smell". In general, alcohols have a higher threshold and contribute less to the flavor, but as the carbon chain length increases, the threshold decreases and more alcohols will contribute to the flavor (Zou, Kang, Liu, Qi, Zhou & Zhang, 2018). The precursors of alcohols are mainly derived from lipid oxidation, especially the oxidative degradation of polyunsaturated fatty acids (Zou et al., 2018). Ethanol and cyclobutanol were detected in 0 kGy, and both of them decreased significantly after irradiation treatment. Especially when the irradiation dose was greater than 3 kGy, cyclobutanol was not detected. This may be due to the lipid degradation after irradiation treatment. However, due to the high threshold of ethanol and cyclobutanol, OAVs were less than 1, so they did not contribute much to the overall flavor of smoked chicken breast. Carotol, 1-nonen-3-ol, 2-hexyl-1-octanol and 1,4-butanediol were detected in irradiated groups. In particular, the OAV of 1-nonen-3-ol was greater than 1 and had an aromatic flavor substance with herbal, citrus, and floral fresh notes, which had also been described as grassy and oily. Aromatic hydrocarbons and phenols have large effects on the formation of the smoked odor which can impart various aromas and flavors to meat products, such as grilled meat, smoked, charred, vanilla, etc (Saldaña et al., 2019). In aromatic hydrocarbons, OAVs of o-xylene, styrene, ethylbenzene, and p-xylene exceeded 1. Among them, p-xylene was detected only in 3, 4, and 6 kGy. The p-xylene has a delicate, slightly sweet, and sometimes pungent and bitter odor. In phenolics, the OAVs of phenol, 3,5-dimethyl-, eugenol, phenol, 2-methoxy-, and estragole were greater than 1. Phenolic compounds are mainly derived from smoke or amino acid degradation. With its pungent phenolic smell and smoky notes, phenol is an aromatic compound that has a powerful aroma (Saldaña et al., 2019). After irradiation treatment, the content of phenol decreased, especially in 2 kGy group. Eugenol has a spicy aroma and several fruit flavors and is one of the important components of the smoky flavor of smoked chicken (Zhang et al., 2021). In a previous work, eugenol was the most abundant phenolic substance in smoked chicken drumsticks, which contributed to the overall smoky flavor (Zhang et al., 2021). Whereas eugenol was only detected at 1 kGy due to the irradiation treatment eliminated this flavor. Phenol, 2-methoxy- were detected when the irradiation dose was greater than or equal to 3 kGy. Phenol, 2-methoxy- as a derivative of phenol, it has a pungent smoky taste.

There were many kinds of terpenes detected in smoked chicken breasts. Of all the flavor compounds detected, 3-carene was the only one with OAVs greater than 1. The

3-carene has a rosin-like odor and is sometimes described as minty, citrusy, or camphoric. However, the content of this compound decreased or disappeared after irradiation treatment. Ketones, amines, esters, and acids likely contribute little to the overall flavor of smoked chicken breasts because of their high OAVs and lower contents. Because of their high OAVs and lower contents, The contents of total acids, total amines, and total ketones were similar between 0 kGy and 2, 3, 4, and 6 kGy. Hexanoic acid, ethyl ester was detected in higher concentrations in the irradiated group, but the threshold value was high and had little effect on the overall flavor. It was worth noting that the 6 kGy group contained a sulfur compound (Sulfurous acid, butyl pentadecyl ester), which smelled sulfurous. Sulfides are usually associated with the degradation of amino acids and the breakdown of side chains, which often leads to the production of off-flavors (Huang et al., 2022). A previous work reported that irradiated smoked duck meat contained three volatile sulfides, allyl sulfide, dipropyl disulfide and allyl disulfide (Jo et al., 2018). In another report, five kinds of sulfur compounds were detected in irradiated frozen yacare caiman meat, which may be one of the important reasons affecting the overall flavor (Cordeiro et al., 2022).

3.9. Taste analysis

Organic acids have a unique sour taste and are important flavor substances in meat products. Their content and type can significantly affect the flavor and texture of meat products. The smoked chicken breast was found to contain four organic acids (tartaric acid, pyruvic acid, malic acid, and acetic acid). As shown in Table 4, the most abundant organic acid was tartaric acid (between 213.22±0.45 and 268.35±1.09 mg/g), followed by pyruvic acid (35.656±0.074~45.95±0.22 mg/g), Malic acid (2.73±0.08~3.19±0.53 mg/g), and acetic acid (0.82±0.51~1.00±0.55). Tartaric and pyruvic acids were major acids found in the smoked chicken breast. Comparatively to the 0 kGy, both tartaric and pyruvic acids decreased with increasing irradiation doses ($P<0.05$), whereas 6 kGy samples increased by 43.34 and 1.82 mg/g. These effects could be attributed to the reaction between organic acids and high-energy molecules generated by irradiation, such as hydroxyl radicals (Wang et al., 2022). Acetic acid content did not change significantly in 0 kGy, whereas malic acid content decreased with increasing irradiation dose. Another work reported that tartaric acid was the main organic acid in flavored pork ribs, and its organic acid content was better preserved after irradiation treatment than heat treatment (Cordeiro, Mouro, Dos Santos & Wagner, 2022).

Taste amino acids and nucleotides have a strong synergistic effect, and this synergistic effect has an important impact on the preservation effect and overall taste of meat products. In addition, nucleotides can also interact synergistically to further enhance the flavor and taste of meat products (Sun et al., 2021). Nucleotides are generally derived from the metabolism of nucleotides. The metabolic pathway of nucleotides is triphosphate (ATP) → adenosine diphosphate(ADP) → adenosine monophosphate (AMP) → inosine monophosphate(IMP) → inosine (HxR) →

hypoxanthine (Hx) (Feng, Jo, Nam & Ahn, 2019). As shown in Table 4, both nucleotides and their degradation products were significantly affected ($P < 0.05$) after gamma irradiation. Specifically, irradiation dose ranging from 2 to 6 kGy led to a 10% to 25% decrease in ADP and a 5% to 17% decrease in AMP. In addition, IMP decreased by 11% and 5% respectively at irradiation doses of 2 kGy and 4 kGy but increased by 6% and 9% respectively at irradiation doses of 3 kGy and 6 kGy. IMP is known to contribute to meaty and savory flavors due to its association with sweet and gustatory complexity (Bai, Fan, Zhu, Wang & Hou, 2022). However, with increasing irradiation dose, the concentration of Hx increased significantly by 1%, 12%, 9%, and 27%. The changes in ADP, AMP, IMP, and Hx observed with increasing irradiation doses indicate the rapid increase of the two final nucleotide degradation products in irradiated smoked chicken breasts. Among the degradation products of nucleotides, Hx has a bitter taste and plays a crucial role in the flavor changes of meat. Deamination of nucleotides can proceed rapidly with the help of free radicals generated by radiation (Feng et al., 2019). In addition, studies have shown that the destruction of muscle fibers will also accelerate the degradation and loss of nucleotides (Zhang et al., 2020).

Free amino acids (FAAs) are essential for the flavor profile of the meat. As these compounds interact with other flavor substances, they shape the overall flavor experience of the meat. The smoked chicken breast, both irradiated and non-irradiated, contained 17 types of FAAs as shown in Table 4. The overall content of FAAs decreased in irradiated smoked chicken breast. The total amount of free amino acids (ΣFAAs) in the 0kGy group was 595.37 mg/100g, while those in the 2 kGy, 3 kGy, 4 kGy, and 6 kGy groups decreased by 55.84, 51.00, 40.94, and 46.28 mg/100g, respectively. In both irradiated and non-irradiated groups, Glu, Ala, Lys, Arg, Ser, and Asp were the most abundant and representative FAAs. The proportion of ΣFAAs accounted for by Glu was the highest, approximately 30%. Studies have shown that Glu is an umami-tasting free amino acid that can not only enhance the taste of meat products but also accelerate the Maillard reaction and form more aromatic compounds (Zhang et al., 2020). Protein degradation induced by irradiation could produce a portion of free amino acids that accelerated the deamination and decarboxylation of amino acids (Jia, Shi, Zhang, Shi & Chu, 2021). Additionally, some free amino acids may have been released from the protein and become more soluble in water, potentially impacting the flavor of the food. Apart from these, the FAAs in meat are responsible for a variety of taste sensations, including sweet, umami, and bitter. Aspartic acid (Asp) and glutamic acid (Glu) provide an umami taste, while serine (Ser), proline (Pro), glycine (Gly), threonine (Thr), and alanine (Ala) contribute to sweetness. Valine (Val), methionine (Met), isoleucine (Ile), phenylalanine (Phe), lysine (Lys), leucine (Leu), arginine (Arg), histidine (His), and tyrosine (Tyr) is associated with bitterness, while L(+)-cysteine (Cys) is considered a non-taste amino acid (Bai et al., 2022). Following irradiation, the umami amino acids in the irradiation group increased, while the levels of sweet and bitter amino acids decreased. Compared to the 0 kGy group, the proportion of ΣFresh flavor nucleotides

increased by 2-4% in the irradiation group, while the proportion of ΣSweetened nucleotides decreased by 1-5%, and the proportion of ΣBitter nucleotides decreased by 1-2%. Among them, there was a significant increase in Glu (umami taste) content in irradiated smoked chicken breasts compared with the 0 kGy group ($P > 0.05$). It increased by 26.31, 1.26, 8.26, and 29.24 mg/100g, respectively. Ala and Arg were related to sweetness, and their levels decreased significantly after irradiation. However, since the contents of Ala and Arg did not exceed their taste thresholds, the taste of smoked chicken breasts is minimally affected by irradiation. Met, His, and Leu are responsible for the bitter taste. A previous study reported that proteins involved in Met and Cys metabolism may produce off-flavors in goat meat after irradiation (Jia et al., 2021). However, in smoked chicken breasts, irradiation was found to decrease the content of bitter-free amino acids and improve its taste.

4. Conclusion

Different doses of gamma irradiation significantly affected the quality and flavor characteristics of smoked chicken breast. Irradiation doses greater than 3 kGy were effective in killing microorganisms and reducing protein oxidation degree, while promoting lipid oxidation. Gamma irradiation at high doses (4 kGy and 6 kGy) also resulted in greater instability of free and bound water and increased muscle fiber gap in smoked chicken breast. Lower doses of irradiation treatment could promote free fatty acids and taste-presenting nucleotides degradation, effectively increase the fresh-tasting amino acids contents and decrease bitter and sweet-tasting amino acids contents. In conclusion, gamma irradiation at a dose less than or equal to 3 kGy not only has a bactericidal effect but also effectively maintains the quality and flavor characteristics of smoked chicken breast.

Acknowledgments

This work was financially supported by the Special Project in the Key Field of Guangdong Universities (2022ZDZX4016), Shaoguan Weng Yuan County Poultry Industry Park (GDSCYY2021-021), Zhongkai College of Agricultural Engineering Punching Supplementary Project "Guangdong Weng Yuan Poultry Science and Technology Small House", Meat pigeon industrial park technology research and development project of Xingning City, China. The authors declare no competing financial interest.

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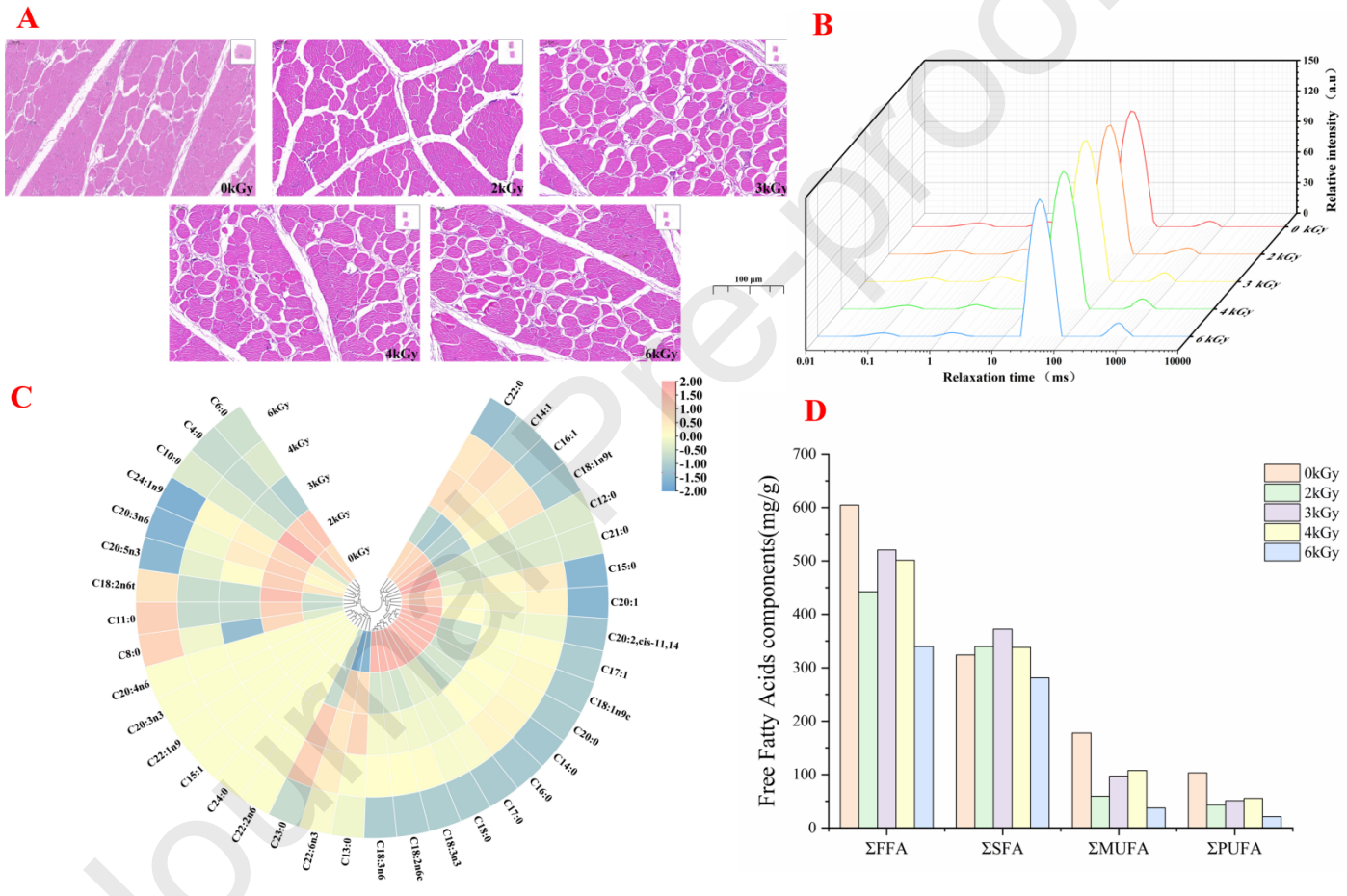
718 **Figure Captions**

719 Figure 1 Effect of the different doses of irradiation treatment on the HE (A),
720 Low-Field Nuclear Magnetic Resonance (LF-NMR) spectroscopy (B), and fatty acids
721 (C/D) of smoked chicken breasts.

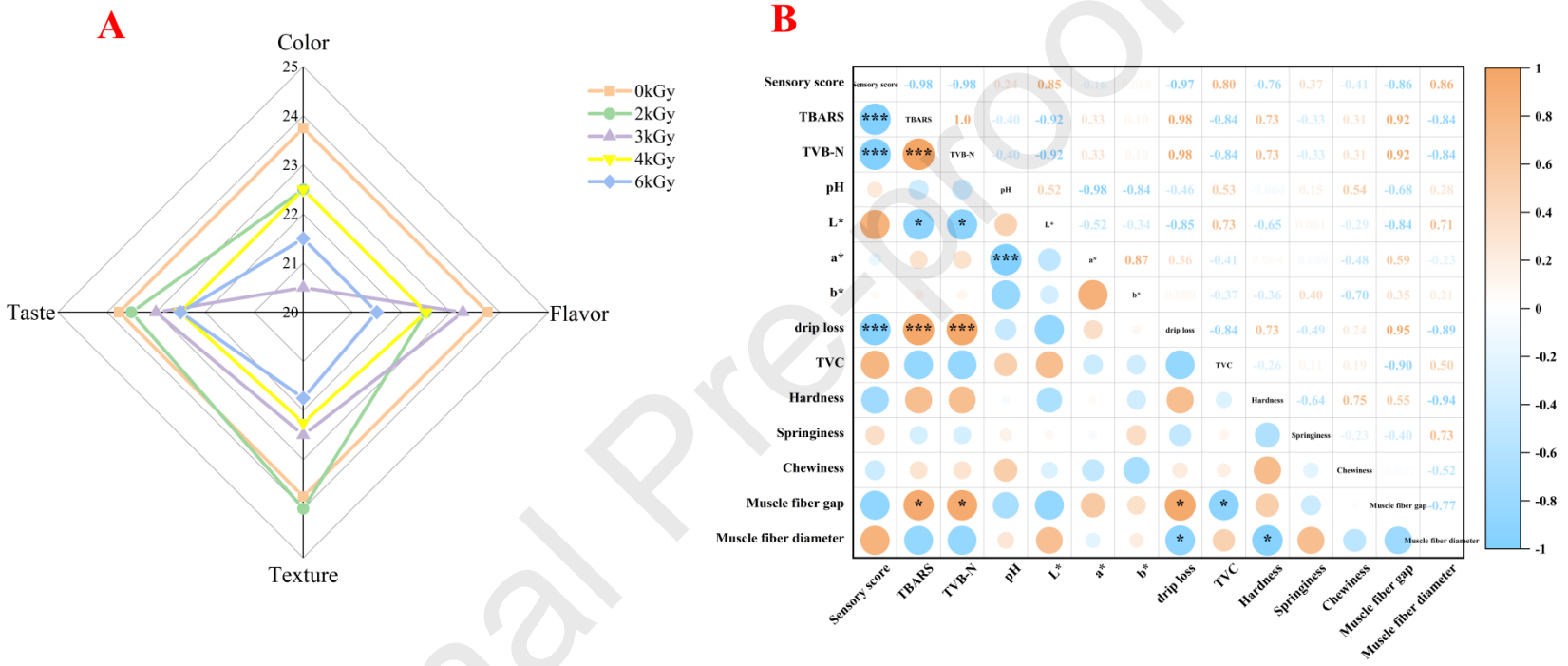
722 Figure 2 Effect of the different doses of irradiation treatment on the sensory
723 evaluation of smoked chicken breasts (A). Correlation analysis of sensory evaluation
724 and physical and chemical indicators of smoked chicken breasts (B).

725 **Figure 1**



726

727 **Figure 2**



728 *** p<=0.05 ** p<=0.01 *** p<=0.01**

729 **Table 1** The physical and chemical indicators of irradiated smoked chicken. Different lowercase letters (a-e) represent significant differences at
730 $P < 0.05$.

Parameter	Irradiation dose (kGy)				
	0	2	3	4	6
***Escherichia coli* (lgCFU/g)**	<10	<10	<10	<10	<10
Total bacterial (lgCFU/g)	2.89±0.02^{a}	2.75±0.05^{a}	2.52±0.12^{b}	1.66±0.00^{c}	0.00±0.00^{d}
pH	6.23±0.02b	6.22±0.01^{b}	6.3±0.01^{a}	6.1±0.02^{d}	6.17±0.02^{c}
TBARS content(mg/kg)	0.1±0.009d	0.13±0.009^{c}	0.18±0.008^{b}	0.19±0.018^{b}	0.22±0.001^{a}
TVB-N content(mg/100g)	9.37±0.14a	9.61±0.21^{a}	8.95±0.36^{b}	8.47±0.08^{c}	8.66±0.16^{bc}
Drip loss(%)	3.99±0.004^{c}	4.42±0.002^{bc}	4.6±0.003^{ab}	4.79±0.002^{ab}	5.00±0.002^{a}
Texture					

731

Hardness (N)	1359.12±57.75^{c}	2106.53±95.90^{b}	2605.67±87.36^{a}	2455.83±40.27^{a}	2146.13±125.12^{b}
Springiness (mm)	0.82±0.00^{a}	0.71±0.01^{b}	0.76±0.07^{ab}	0.75±0.05^{ab}	0.76±0.07^{ab}
Chewiness (N)	1060.16±56.00^{c}	1195.98±85.21^{b}	1664.33±61.49^{a}	1244.30±36.90^{ab}	1148.27±94.10^{bc}
HE					
Muscle fiber gap (μm)	3.01±0.38^{a}	4.71±0.6^{b}	4.7±1.18^{b}	7.14±0.8^{c}	7.91±0.86^{c}
Muscle fiber diameter (μm)	61.91±6.56^{a}	58.14±5.58^{b}	57.19±3.97^{d}	56.82±3.08^{e}	57.29±2.47^{c}
Color					
L*	50.52±0.73^{a}	50.90±1.09^{a}	49.89±0.52^{a}	46.63±0.89^{c}	48.15±0.45^{b}
a*	14.76±0.97^{b}	14.49±0.92^{b}	14.20±0.85^{b}	16.57±0.75^{a}	15.53±0.84^{ab}
b*	33.33±0.83^{ab}	30.17±3.43^{b}	30.30±2.75^{b}	36.73±2.26^{a}	32.99±1.63^{ab}

732 **Table 2** LF-NMR spin–spin relaxation time (T_2) and peak proportion (P) of the chicken breast.

Irradiation done（kGy）	T_2 relaxation time distribution				Proportion of T_2 relaxation time peak area			
	T_{21a}	T_{21b}	T_{22}	T_{23}	P_{21a}	P_{21b}	P_{22}	P_{23}
0	0.105	1.42	31.4	603	1.37	1.94	92.69	4.06
2	0.113	1.51	35.8	685	1.43	1.83	92.31	4.46
3	0.115	1.51	36.1	667	1.31	1.83	91.67	5.03
4	0.115	1.51	38.4	721	1.28	1.69	91.37	5.68
6	0.114	1.51	38.1	731	1.19	1.57	90.77	6.47

734 **Table 3** Changes in volatile compounds (mg/kg) of irradiated smoked chicken breast.

Compound group	Volatile compounds	CAS number	RI	Content(mg/kg)					Odor description
				0 kGy	2 kGy	3 kGy	4 kGy	6 kGy	
Aldehydes									
	△Hexanal	000066-25-1	833	8.62±4.36	7.16±3.21	11.25±6.16	3.52±4.98	10.24±2.95	Pungent, pungent, spicy flavor
	△Nonanal	000124-19-6	1121	25.74±3.35	22.1±0.7	28.35±6.99	nd	33.62±3.86	Oily, citrusy taste
	8-Octadecenal	056554-94-0	/	1.02±0.01	nd	nd	nd	nd	Greasy, meaty, fishy
	△Heptanal	000111-71-7	955	0.15±0	nd	nd	nd	nd	Fruity, putrid
	△Octanal	000124-13-0	102	nd	nd	2.2±1	nd	1.65±0.2	Aromatic, milky

			6						
	△Decanal	000112-31-2	1169	nd	nd	4.18±0.05	nd	6.64±0.97	Aromatic, fruity, fishy
	5-Ethylcyclopent-1-enecarboxaldehyde	036431-60-4	1477	nd	nd	nd	nd	2.88±0	Aromatic, smoky
Alcohols									
	Ethanol	000064-17-5	159	5.35±1.21	1.52±0.51	3.11±0.19	5.83±1.31	2.35±0.03	Pungent, slightly sweet, slightly bitter
	dl-Menthol	000089-78-1	1500	nd	1.74±0.02	3.15±0.01	nd	nd	Peppermint scent
	Carotol	000465-28-1	202	nd	0.23±0.04	nd	nd	nd	Woody, spicy, aromatic
	△1-Nonen-3-ol	021964-44-3	1202	nd	nd	nd	2.14±0.02	nd	Herbal, aromatic, citrus

	2-Hexyl-1-octanol	019780-79-1	2200	nd	nd	nd	3.67±0.39	nd	Floral, fruity, grape
	1,4-Butanediol	000110-63-4	320	nd	nd	nd	nd	105.25±3.56	Sweet, subtle aroma
	Cyclobutanol	002919-23-5	1600	0.04±0	0.02±0.01	nd	nd	nd	Woody, herbal scent
Aromatic hydrocarbons									
	△o-Xylene	000095-47-6	1100	34.49±1.48	17.34±17.3	nd	5.33±0.1	nd	Sweet, oily, aromatic
	△Styrene	000100-42-5	240	18.21±1.09	15.49±6.68	9.5±5.78	39.11±6.91	10.64±6.58	Bitter, caramel, smoky
	△Ethylbenzene	000100-41-4	681	4.63±0.22	nd	nd	5.33±0.1	3.21±0.02	Sweet, aromatic

	△p-Xylene	000106-42-3	732	nd	nd	29.71±1.37	55.97±7.29	19.08±14.5	Lightly aromatic
	3-Methyl-3-hexene	003404-65-7	701	nd	nd	2.3±0.07	nd	nd	Aromatic, minty, spicy
	Toluene	000108-88-3	298	nd	nd	nd	nd	10.23±0.02	Strongly sweet, bitter
	2-Ethyl-3-methylcyclopent-2-en-1-one	1000423-46-8	1123	nd	nd	nd	nd	0.16±0.01	Fruity, herbal, sweet
Phenols									
	△Phenol	000108-95-2	1225	35.23±4.73	13.01±2.41	23.46±0.93	39.16±5.25	23.62±1.62	Pungent phenolic odor
	Phenol, 2-methyl-	000095-48-7	1110	14.64±5.19	2.96±4.09	5.25±0.19	29.34±2.8	8.14±0.38	Coke, smoky taste
	△Phenol, 3,5-dimethyl-	000108-68-9	1599	8.39±0.16	nd	nd	nd	nd	Phenolic aroma and bitterness

	2-Methoxy-5-methylphenol	001195-09-1	2020	9.34±0.98	2.96±4.09	7.02±0	nd	7.76±0.25	Smoky, woody, aromatic
	△Eugenol	000097-53-0	1576	0.34±0.11	nd	nd	nd	nd	Pungent, bitter, aromatic odor
	△Phenol, 2-methoxy-	000090-05-1	1059	nd	nd	22.75±2.83	47.03±5.41	26.17±0.64	Sweet, bitter
	Estragole	000140-67-0	1195	nd	nd	0.25±0	nd	nd	Pungent, sweet, herbal
Esters									
	Sarcosine, N-valeryl-, pentyl ester	1000321-56-2	1809	0.13±0.15	nd	nd	nd	nd	Candied, fruity, floral
	1,3-Dioxolane	000646-06-0	594	0.01±0	0.98±0.01	nd	nd	nd	Fresh, sweet
	Carbonic acid, decyl undecyl ester	1000383-16-	242	0.48±0.11	1.34±0	nd	nd	0.68±0.01	Fruity, grapefruit, sweet, mellow

		0	8					
	Hexanoic acid, ethyl ester	000123-66-0	1800	28.37±0.39	nd	10.99±1.79	nd	nd	Vanilla, creamy, fruity aroma
	Dimethyl 3-sulfinopropionate	085939-98-6	/	nd	0.12±0	nd	nd	nd	Broth, miso
	Oxalic acid, decyl 2-ethylhexyl ester	1000309-39-3	/	nd	1.57±0	nd	nd	nd	Citric acid salt flavors
	Carbonic acid, heptyl methyl ester	1000314-61-9	1058	nd	nd	0.69±0.01	nd	nd	Champagne flavor, fruit flavor
	Acetic acid, 3,7,11,15-tetramethyl-hexadecyl ester	1000193-63-0	1825	nd	nd	0.49±0.01	nd	nd	Light flavor
	3,7-Dimethyloctyl acetate	020780-49-8	1077	nd	nd	nd	1.27±0	nd	Fruity flavor
Terpenes									

1-Chloroeicosane	042217-02-7	2264	0.64±0.55	nd	nd	nd	nd	Pine wood odor
.alpha.-Pinene	000080-56-8	1069	1.02±0.01	nd	2.08±0.36	nd	0.7±0.21	Pine needles, pine resin scent
1-Decene	000872-05-9	988	1.04±0.04	0.53±0.35	nd	nd	nd	Fruity, herbal, floral
(+)-3-Carene	000498-15-7	1170	7.21±0.04	7.51±0.07	5.34±0	nd	nd	Woody fragrance
Longifolene	000475-20-7	2060	0.61±0	4.02±3.02	2.43±1.84	nd	0.54±0.02	Pine woody fragrance.
△3-Carene	013466-78-9	1350	10.63±0.18	nd	nd	9.49±0.09	nd	Pine woody fragrance
1-Hexacosene	018835-33-1	2596	nd	0.19±0.11	nd	0.57±0.01	2.47±0.03	Waxy fragrance

(+)-2-Bornanone	000464-49-3	1600	nd	0.46±0.01	0.53±0.03	nd	nd	Aromatic, sweet
1-Tetracosene	010192-32-2	1990	nd	0.37±0.02	nd	nd	nd	Lightly oily smell
Cedrol	000077-53-2	1792	nd	nd	0.45±0.03	nd	0.46±0.02	Woody, minty
D-Limonene	005989-27-5	1129	nd	nd	4.32±0.06	nd	7.03±3.59	Citrus, crisp, spicy
3-Methyl-3-hexene	003404-65-7	701	nd	nd	2.3±0.07	nd	nd	Aromatic, oily, roasted aroma
1-Tetradecene	001120-36-1	1388	nd	nd	nd	2.2±1.99	nd	Oily
5-Ethyl-1-nonene	019780-74-6	/	nd	nd	nd	0.45±0.02	nd	Oily, herbal, fruity
1,7-Hexadecadiene	125110-62-5	/	nd	nd	nd	nd	0.99±0	Aromatic, oily

Ketones									
	Butylated Hydroxytoluene	000128-37-0	150	1.61±0.06	nd	1.91±0.1	nd	2.82±0.35	Slightly bitter taste
	Piperitenone oxide	035178-55-3	250	nd	0.58±0.1	nd	nd	nd	Peppermint aroma
	2-Acetylcyclopentanone	001670-46-8	100	nd	nd	1.14±0.04	nd	nd	Roasted sweet, spicy flavor
	Acetophenone	000098-86-2	932	nd	nd	nd	nd	1.67±0.01	Bittersweet
Amines									
	Methylpent-4-enylamine	005831-72-1	1417	0.25±0.27	0.04±0	0.09±0.09	nd	nd	Ammonia odor and fishy smell
	N-Methyldodecylamine	1000426-51-1	2055	0.02±0.01	nd	nd	nd	0.02±0.14	Amine odor, fishy smell
	n-Hexylmethylamine	035161-70-7	871	nd	nd	nd	nd	0.04±0.01	Stimulating, ammonia odor, fishy

Sulfide									
	Sulfurous acid, butyl pentadecyl ester	1000309-18-2	/	nd	nd	nd	nd	5.73±0.08	Sulfur smell
Acids									
	Fumaramic acid	002987-87-3	1289	0.1±0	nd	nd	nd	nd	Sour
	Tartronic acid	000080-69-3	848	nd	nd	27.65±0.32	nd	28.76±0.01	Sour
others									
	Octacosane	000630-02-4	1930	nd	3.01±0	nd	2.3±0.02	nd	Slightly oily fragrance scent
	Cyclohexadecane	000295-65-8	1775	nd	0.33±0.07	nd	nd	nd	Fresh, slightly sweet odor

735 RI: retention index; △: OAV＞1; Odor description was obtained from the Good Scents Company Information System
736 (http://www.thegoodscentscompany.com/).

737 **Table 4** Effect of the different doses of irradiation treatment on the content of organic acids, nucleotides and free amino acids of smoked chicken
738 breasts.

Parameter	Irradiation dose (kGy)				
	0	2	3	4	6
Organic acids					
Tartaric acid	225.01±0.20^{ab}	225.21±0.42^{ab}	217.48±1.03^{b}	213.22±0.45^{b}	268.35±1.09^{a}
Pyruvic acid	44.13±0.26^{ab}	38.58±5.05^{c}	40.77±0.26^{bc}	39.48±0.13^{c}	45.95±0.22^{a}
malic acid	3.36±0.63^{a}	3.25±0.49^{a}	3.26±0.17^{a}	2.73±0.07^{a}	3.06±0.07^{a}
Acetic acid	0.90±0.58^{a}	0.93±0.24^{a}	0.82±0.51^{a}	0.96±0.47^{a}	1.00±0.55^{a}
Σ Organic acids	273.4	267.98	262.34	262.34	318.36

Nucleotides					
ADP	12.19±3.35^{a}	10.93±0.14^{a}	10.19±0.64^{a}	9.11±3.40^{a}	9.49±0.25^{a}
AMP	19.23±0.19^{a}	11.28±7.34^{b}	15.99±0.07^{ab}	15.02±1.99^{ab}	18.22±0.17^{a}
IMP	1.43±0.12^{ab}	1.28±0.01^{b}	1.51±0.18a^{b}	1.35±0.18a^{b}	1.56±0.02^{a}
Hx	3.39±0.99^{b}	3.42±0.00^{b}	3.78±0.01a^{b}	3.78±0.01a^{b}	4.29±0.02^{a}
Free amino acids (FAAs)					
Asp	37.43±0.01^{a}	29.84±0.17^{c}	33.53±0.65^{b}	33.71±0.00^{b}	30.29±0.00^{c}
Thr	31.04±0.00^{a}	25.02±0.17^{b}	27.69±0.40^{ab}	29.47±3.31^{ab}	29.14±5.25^{ab}
Ser	38.76±0.02^{a}	30.09±0.00^{e}	35.01±0.00^{b}	33.29±0.17^{c}	30.40±0.04^{d}
Glu	129.34±0.18^{e}	155.64±1.73^{b}	130.60±1.18^{d}	137.59±0.17^{c}	158.58±0.02^{a}

Gly	27.84±0.35^{a}	20.13±0.00^{e}	24.17±0.02^{b}	22.84±0.01^{c}	20.34±0.02^{d}
Ala	51.78±0.00^{a}	42.45±0.17^{e}	47.54±0.01^{b}	45.34±0.10^{c}	43.06±0.00^{d}
Cys	1.52±0.02^{c}	1.55±0.00b^{c}	1.87±0.06^{a}	1.52±0.00^{c}	1.59±0.02^{b}
Val	28.02±0.01^{a}	24.34±0.00^{d}	25.46±0.20^{bc}	26.40±1.67^{b}	24.62±0.00^{bc}
Met	14.67±0.00^{a}	10.12±0.17^{d}	13.12±0.20^{b}	11.09±0.00^{c}	9.43±0.00^{e}
Ile	19.52±0.04^{a}	17.24 ±0.03^{d}	17.55±0.00^{c}	17.94±0.00^{b}	17.59±0.18^{c}
Leu	35.32±0.04^{a}	30.51±0.35^{e}	31.44±0.00^{c}	32.14±0.33^{b}	31.12±0.00^{d}
Tyr	25.76±0.53^{a}	22.09±0.07^{d}	23.53±0.34^{b}	22.92±0.00^{c}	22.22±0.04^{d}
Phe	18.64±0.04^{a}	18.06±0.00^{c}	18.10±0.12^{bc}	17.95±0.10^{d}	18.18±0.00^{b}
Lys	47.37±1.59^{a}	41.07±0.52^{ab}	36.45±0.06^{ab}	41.56±3.64^{b}	40.86±0.18^{b}

His	22.45±0.05[a]	17.97±0.69[d]	19.45±0.06[b]	20.06±0.02[c]	17.70±0.02[d]
Arg	44.09±0.62[a]	34.20±0.09[e]	38.52±0.04[c]	40.54±0.17[b]	34.58±0.00[d]
Pro	21.82±0.09[a]	19.22±0.00[e]	20.36±0.00[b]	20.06±0.00[c]	19.38±0.01[d]
Σ Fresh flavor nucleotides	166.77	185.48	164.13	171.3	188.87
Σ Sweetened nucleotides	243.35	195.45	218.75	217.95	201.52
Σ Bitter nucleotides	183.74	157.05	159.63	163.65	157.11
Σ FAAs	5964.39	5400.59	544.37	554.43	5453.99

Author contribution

Article title: **Effect of gamma irradiation treatment on microstructure, water mobility, flavor, sensory and quality properties of smoked chicken breast**

Xiaoxia Huang designed the study, prepared and wrote the original manuscript.

Yun You, Weidong Bai, Bifeng Lan, and Junshi Wu modified the Tables and Figures, references and revised the English writing.

Qiaoyu Liu and Hao Dong provided the financial support. They also reviewed, supervised, revised and finalized the manuscript.

Declaration of interests

☑ 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.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Highlights

- The quality of irradiated smoked chicken breast was systematically analyzed
- Irradiation doses ≤ 3 kGy maintain quality and flavor of smoked chicken breast
- Irradiation doses＞3 kGy could reduce protein oxidation and promote lipid oxidation
- 6 kGy of irradiation negatively affect quality and flavor of smoked chicken breast