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Research Article

Effect of Irradiation on Quality of Vacuum-Packed Spicy Beef Chops

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To develop an alternative pasteurization process for the spicy beef jerky (SBJ), it was treated with irradiation doses of 0, 0.5, 1.5, 3, 4, 6, and 8 kGy and the sensory attributes, texture properties, drip loss, and the protein biological efficiency were studied. The results showed that lightness, drip loss, and off-odor of SBJ increased, while the hardness, chewiness, gumminess, color preference, and taste of SBJ decreased with the increase in irradiation dose. This tendency was obvious as the irradiation dose increased to 6 kGy and 8 kGy. The possible reason for these quality changes might be due to the free radicals produced by irradiation. This speculation is supported by the decrease of the content of capsanthin and the increase of the content of TBARS of SBJ with the increase in irradiation dose. The plate counts of treated SBJ indicated that 4 kGy was suitable for pasteurization of SBJ.

1. Introduction

Spicy beef jerky (SBJ) is a popular meat product in China, which is being consumed or mostly being bestowed as a snack food. With the rapid development of tourism industry in China, more and more SBJ is sold as local specialty with a huge market demand [1, 2]. In this situation, quality and food safety of SBJ become very important. In order to extend shelf life of SBJ and to ensure food safety, the sterilization process of SBJ received more attention [3]. Generally, steam process (121.1°C, 0.355 MPa) is used as secondary or last sterilization step to treat SBJ after it was vacuum packed [4, 5]. The steam process is batch operation which consumes more energy and degrades the quality of meat products [6, 7]. Therefore, new and alternative processes are expected to be developed for sterilization of SBJ.

Irradiation has been considered as the best method for control of pathogenic microorganisms in meat and meat products [8], which also improves the safety of a wide range of products and extends their useful life [9–13]. In 1997, the FDA approved using irradiation to treat meat for controlling the disease causing microorganisms, such as *Escherichia Coli*, *Salmonella*, *Listeria* and other food-borne pathogens [14]. Irradiation of food up to an overall dose of 10 kGy is accepted in several countries for commercial food processes [15]. Recently, vacuum-packed lamb meat was irradiated to reduce spoilage bacteria [16]. Hams were irradiated using ^{60}Co gamma-ray at 0, 2.5, and 5 kGy to extend shelf life [17]. Wuxi meat gluten was irradiated for sterilization against bacterial spoilage and to prolong shelf life [18]. However, fewer investigations on effect of irradiation on quality of SBJ were reported. Considering that the quality of meat products is one of the major concerns for adopting irradiation of food products [19], the objective of this research was to investigate effect of irradiation on quality of SBJ.

2. Materials and Methods

2.1. Materials. Yak longissimus thoracis muscles (from 12th thoracic vertebrae to 5th lumbar vertebrae) were excised from the right side of carcasses. It was frozen (−18°C) and shipped within 4 hours to our laboratory from Chengdu Wutian Food Co., Ltd. Sterile polyester polyethylene (PET/Poly) bags (150 mm × 200 mm, thickness 0.08 mm) were purchased from Chengdu Xin Shun Plastic Products Co., Ltd. Media used for the microbiological analyses were purchased from LandBridge Co., Ltd., Beijing, China. Capsorubin standard, trichloroacetic acid (TCA), butylated hydroxytoluene (BHT), and thiobarbituric acid (TBA) were purchased from Sinopharm Chemical Reagent Co. Ltd. (Shanghai, China). All other chemicals and solvents were of the highest commercial grade and obtained from Chengdu Changzheng Glass Co. Ltd. (Chengdu, China)

2.2. Methods

2.2.1. Preparation of SBJ. The frozen yak meat was thawed in refrigerator (Haier BCD-460WDGZ, Qingdao, China) at 0 to 4°C for 24 h. The thawed yak meat was pretreated by removing any visible fat, tendon muscle membrane, and the edge meat whose color becomes white. The pretreated meat was washed with ice and running water at less than 10°C for 2 h to remove blood and to reduce smell. The washed meat was drained for 3 h at 4 to 8°C in the refrigerator (Haier BCD-460WDGZ, Qingdao, China). Four kilograms of the washed yak meat was boiled in a pressure cooker (internal pressure 80 kPa, 117-118°C) for 1 h. The boiled meat was sliced into chops having length of 20 ± 1 mm, width of 10 ± 1 mm, and thickness of 5 ± 1 mm.

The meat chops were stir-fried in soybean oil (Yihai Kerry Food Marketing Limited, Shanghai, China) with a mass ratio of meat and oil of 5 : 1 at 120 ± 3°C for 5 min and then mixed with meat and seasoning mixture in mass ratio of 1 : 0.425. The seasoning mixture is composed of salt, monosodium glutamate (MSG), sugar, pepper powder, and Szechuan pepper corns in ratio of 14.29%, 7.14%, 57.14%, 10.71%, and 10.71%, respectively. The obtained product was divided into 20 equal parts. Each part was packaged with DZ-500-2S double chamber vacuum packing machine (Dajiang Machinery Equipment Co., Ltd.) and sealed aseptically in polyethylene bags.

2.2.2. Irradiation. Packaged SBJ samples were gamma-irradiated at Chengdu Xinjin Biochemical Engineering Research Institute (Chengdu, China) inside a package irradiator (Gamma Cell 220, NORDION Intl. Inc., Ontario, Canada) with a ^{60}Co source at a rate of 5 kGy/h at 12 ± 0.5°C. The dose was established using 5-mm diameter alanine dosimeters (Bruker Instruments, Rheinstetten, Germany). The irradiation doses in this study were 0, 0.5, 1.5, 3, 6, and 8 kGy and the actual doses were within ±0.2 kGy of the target dose. After irradiation, the SBJs were stored at 4 to 8°C in refrigerator (Haier BCD-460WDGZ, Qingdao, China). All analyses were carried out within one week.

2.2.3. Color Analysis. Color of SBJ was measured with the instrument and method reported by Zhang et al. [20] and Zhang et al. [21]. The packaged SBJ samples were loaded on the sample table. The height between the sample table and charge-coupled device (CCD) camera was adjusted to 170 ± 5 mm, and a computer was used to take images of the SBJ samples. The gathered images were saved in .jpg format with Adobe Photoshop CS4 (Adobe Systems Inc., San Jose, CA). The digital image of SBJ samples was cut into length of 10 mm and width of 10 mm. Imread function in the software MATLAB v7.0 (MathWorks, Natick, MA) was used to input the digital image. The CIE L^*, a^*, and b^* coordinates of SBJ samples were calculated according to the digital images of SBJ samples. Color analyses were run in six replicates. L^* represents a perfect reflecting diffuser and the value scope for L^* is between 0 and 100. Positive a^* value represents red and negative a^* value represents green. Positive b^* value represents yellow and negative b^* value represents blue.

2.2.4. Drip Loss. Drip loss of the SBJ samples was determined with image analysis method. The unopened SBJ package was fixed onto stainless table and a BenQ S1430 digital camera was used to take picture of the SBJ samples. The distance between the camera and sample was fixed at 300 mm. According to the pictures, the area of juice around the beef pieces and the area of the beef pieces were determined with Adobe Acrobat XI Pro (Adobe, USA). The drip loss (%) was calculated by $S_{\text{area of juice around the yak pieces}}/S_{\text{area of the yak pieces}} \times 100$.

2.2.5. Texture Profile. Texture profile of the SBJ was analyzed using a texture analyzer, TA-XT2i (Stable Micro Systems, Surrey, UK) according to the method reported by Zhang et al. [22] with slight modification. SBJ samples were equilibrated and the texture was measured at room temperature (25~30°C). At least nine SBJ chops (length of 20 mm, width of 10 mm, and thickness of 5 mm) were equilibrated and evaluated at room temperature (25~30°C). The SBJ sample was axially compressed to 30% of original height with speed of 2.0 mm/s by a P45 cylindrical plunger. Force-time deformation curves were derived with a 25 kg load cell. Hardness (g), gumminess, and chewiness were determined.

2.2.6. Sensory Analysis. Sensory attributes of the SBJ were analyzed according to method of Kanatt et al. [23] and Khattak and Simpson [24]. The sensory attributes were evaluated within one day after the irradiation treatment. Off-odor, color preference, and taste of the SBJ were used as sensory indexes, and a 10-point numerical scale was adopted to indicate quality changes. The scores were assigned: as for off-odor: 0: normal, 2: little smell, 4: slightly obvious, 6: obvious, 8: more obvious, and 10: extremely obvious; as for color preference, 0: extremely poor, 2: very poor, 4: poor, 6: acceptable, 8: good, and 10: excellent; as for taste, 0: normal, 2: little changed, 4: slightly changed, 6: poor, 8: very poor, and 10: extremely poor. Each panelist received six coded samples (one nonirradiated and five irradiated samples; one at each dose). All the SBJ samples were tasted by 25 persons. Before tasting, the SBJ samples were kept in air for 1 h to let the

temperature of the samples be in equilibrium with that of the environment. Each panelist independently evaluated the SBJ samples.

2.2.7. Determination of Capsorubin. The content of capsorubin in the SBJs was determined with the method of Xu et al. [25] with slight modification. The SBJ sample was manually chopped into 1 mm and separated with 18-mesh sieve. The chopped sample (20 g) was dissolved in 80 mL acetone at pH 9.0, extracted at 40°C for 3 h. Wavelength absorbance of the acetone extract was measured at 460 nm. The amount of capsorubin was calculated using the capsorubin standard curve. The content of the capsorubin was expressed as mg capsorubin per g of the SBJ.

2.2.8. Measurement of Lipid Oxidation. TBARS (Thiobarbituric Acid Reactive Substances) produced from lipid oxidation were determined according to the method used by Alasnier et al. [26]. A 4 g portion of each SBJ sample was blended with 16 mL of 5% trichloroacetic acid (TCA) and BHT (10 μg BHT/g of lipids). It was then filtered through Whatman filter (number 4). The same amounts of the filtrate and 0.02 M TBA were heated in a boiling water (95°C) bath for 30 min, and, after cooling the contents, the absorbance was measured at 532 nm. The amount of TBARS was expressed as mg malonaldehyde per kg of SBJ.

2.2.9. Microbial Analyses. Samples (25 g) in duplicate from the irradiated and nonirradiated control batches were aseptically homogenized for 1 min with sterile saline (225 mL) in a Stomacher (Seward Medical, UK). Appropriate serial dilutions of the homogenate were carried out. Total plate count (by pour plate method) was determined using Plate Count Agar incubated at 30°C for 48 h. The *Escherichia coli* was measured according to ISO 16649-1: 2001 [27] and ISO 16649-2: 2001 [28].

2.2.10. Statistical Analysis. Analysis of variance was performed and mean comparisons were run by Duncan's multiple range test using the SAS system for Windows 9.0 (SAS Institute, Cary, NC). Excel 2010 was used to analyze the regression. All experiments were replicated at least three times.

3. Results and Discussion

3.1. Effect of Irradiation on Color of SBJ. Color of meat products is an important quality attribute that directly influences consumer's acceptance [29]. Effect of irradiation on color of SBJ (Figure 1) indicated that lightness (L^*) of SBJ was significantly ($P < 0.05$) increased as the irradiation energy increased to 6 kGy and 8 kGy. Similar result was reported as the dry-cured loins were irradiated [30]. Redness (a^*) of SBJ was significantly ($P < 0.05$) decreased as the irradiation energy increased to 8 kGy. The redness of irradiated meat products seems to change differently with food category. The redness of hams [17], cooked pork sausage [31], and wrapped beef patties [32] was changed similarly like SBJ when they were irradiated, but the redness of dry-cured loins [30] and

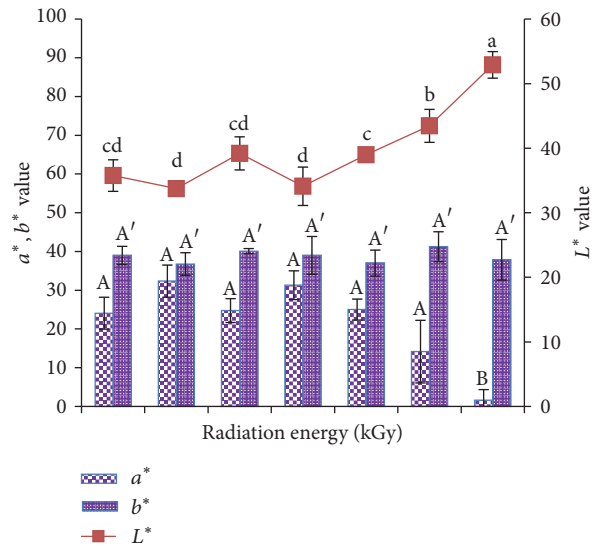

Figure 1: Effect of irradiation on color of SBJ. L^* represents lightness; positive a^* value represents red; positive b^* value represents yellow. Values are represented as mean ± SD. Significance was tested by Duncan Multiple Range Test at $P < 0.05$, and values with the same superscript were found not significantly different from each other.

raw turkey breast and thigh meats [33] was increased as the irradiation dose was increased. Values of b^* (yellowness) of SBJ were not significantly ($P > 0.05$) changed as the irradiation energy increased. Similar phenomena appeared as vacuum-packed lamb meat was irradiated [16].

Irradiation can generate free radicals and induce reactions among food components [34], including oxidation of metals, oxidation/reduction of carbonyls to/from hydroxyl derivatives, and elimination of unsaturation bonds [34–36]. These reactions resulted in significant color change of meat [37–39]. The SBJ was a mixture of meat, soybean oil, salt, and spicy ingredients. The free radicals produced by irradiation led to chemical reactions, such as ferrous ions in heme oxidized to ferric iron, and capsanthin in pepper powder was decomposed into other chemicals. These chemical reactions might have resulted in the increase of L^*, and decrease of a^* with the increase in irradiation energy. The color of SBJ is burgundy. Yellowness ($+b^*$) is not the primary color of SBJ. Therefore, b^* changed slightly compared to a^* or L^* as SBJ was irradiated. This may be the possible reason that b^* of SBJ was not significantly ($P < 0.05$) influenced with the increase in irradiation dose.

3.2. Effect of Irradiation on Drip Loss of SBJ. Effect of irradiation on drip loss of SBJ was shown in Figure 2. Data in Figure 2 indicated that the drip loss of SBJ irradiated with 3 kGy and 4 kGy was significantly ($P < 0.05$) higher than those of SBJ irradiated with 0, 0.5, and 1.5 kGy. The drip loss of SBJ irradiated with 6 kGy was significantly ($P < 0.05$) higher than that of SBJ irradiated with 3 and 4 kGy and the drip loss of SBJ irradiated with 8 kGy was significantly ($P < 0.05$) higher than that of SBJ irradiated with 6 kGy. The drip loss of SBJ and the irradiation energy showed quadratic correlation

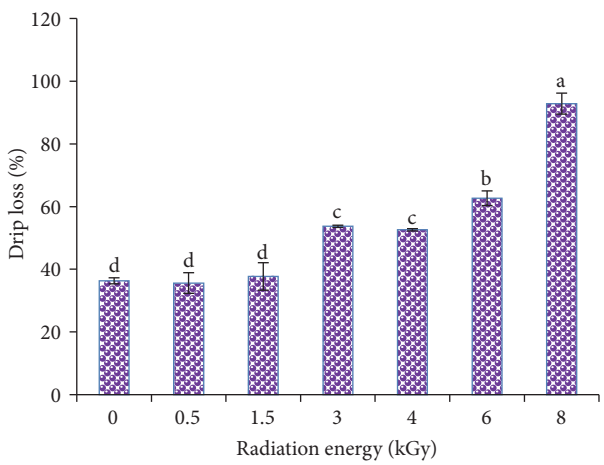

Figure 2: Effect of irradiation on drip loss of SBJ. Values are represented as mean ± SD. Significance was tested by Duncan Multiple Range Test at $P < 0.05$, and values with the same superscript were found not significantly different from each other.

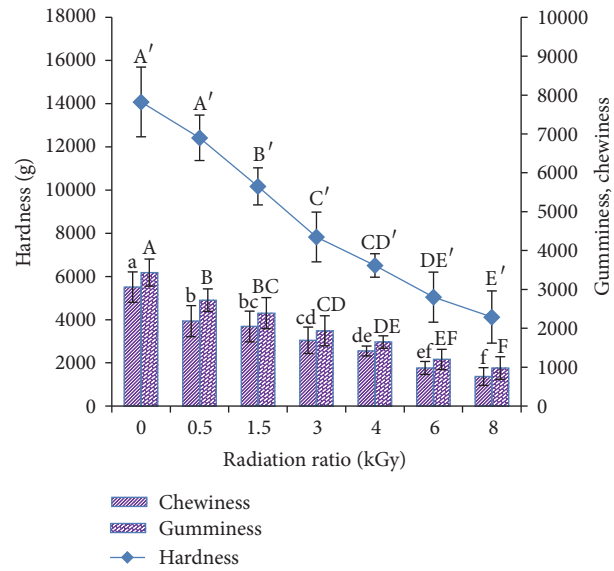

Figure 3: Effect of irradiation on texture profile properties of SBJ. Values are represented as mean ± SD. Significance was tested by Duncan Multiple Range Test at $P < 0.05$, and values with the same superscript were found not significantly different from each other.

($R^2 = 0.959$). Similar tendency appeared as the pork fillet [40] and pork loins were irradiated [41].

High drip loss means more fat oxidation and meat protein damage happened in irradiated meat product [42, 43]. These chemical effects of irradiation result in breakage of texture and decrease of water holding capacity of meat products [40]. The drip loss of SBJ in Figure 2 suggested that irradiation energy higher than 3 kGy resulted in significant ($P < 0.05$) damage to the quality of SBJ, and further quality degradation happened as the irradiation energy was increased to 6 kGy and 8 kGy. This speculation is consistent with the results in Figure 1, which shows that L^* of SBJ was increased and a^* of SBJ was decreased with the increase in irradiation energy.

3.3. Effect of Irradiation on Textural Properties of SBJ. Effect of irradiation on texture properties of SBJ was shown in Figure 3. Data in Figure 3 indicated that the hardness, chewiness, and the gumminess of SBJ decreased significantly ($P < 0.05$) with the increase in irradiation dose. The texture properties of SBJ and the irradiation energy showed quadratic correlation. The coefficient between the irradiation energy with hardness, chewiness, and gumminess are $R^2_{\text{hardness}} = 0.996$, $R^2_{\text{chewiness}} = 0.937$, and $R^2_{\text{gumminess}} = 0.994$, respectively. Similar results were reported as pork loin was irradiated [44].

Irradiation resulted in changes of texture and damage to meat proteins and both of them became more serious with irradiation energy increase [34, 40]. This may be the possible reason that the hardness, the chewiness, and the gumminess of SBJ decreased with the increase in irradiation dose. Textural properties are important to food product development [45]. The results in Figure 3 suggest that proper irradiation energy dosage should be chosen as the irradiation process is used to pasteurize SBJ.

3.4. Effect of Irradiation on Sensory Attributes of SBJ. Effect of irradiation on sensory attributes of SBJ was shown in Figure 4. The results (Figure 4) indicated that the color

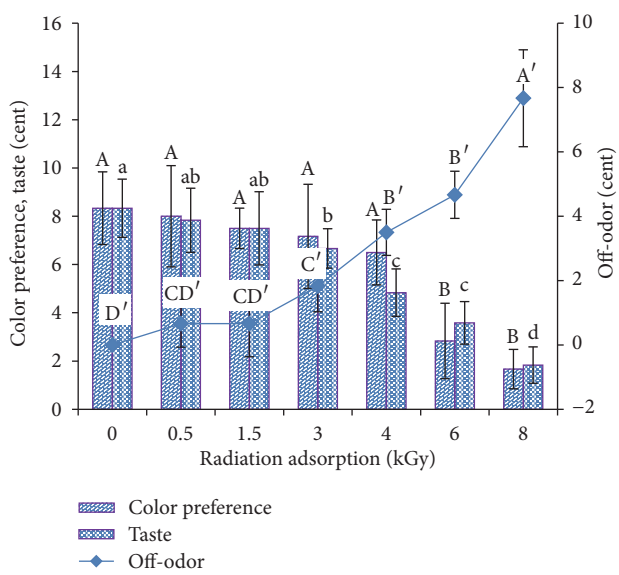

Figure 4: Effect of irradiation on sensory attributes of SBJ. Values are represented as mean ± SD. Significance was tested by Duncan Multiple Range Test at $P < 0.05$, and values with the same superscript were found not significantly different from each other.

preference of SBJ decreased significantly ($P < 0.05$) as the irradiation dose increased to 6 kGy and 8 kGy and the taste of SBJ decreased significantly ($P < 0.05$) as the irradiation dose increased to 4 kGy, 6 kGy, and 8 kGy. There was significant ($P < 0.05$) off-odor as the SBJ was irradiated with 4 kGy, 6 kGy, and 8 kGy, respectively. Similar color and off-odor changes were reported as the Jinluo ham was irradiated with ^{60}Co [17]. The sensory quality changes in Figure 4 are consistent with the conclusion of Ahn et al. [46] and Smulders

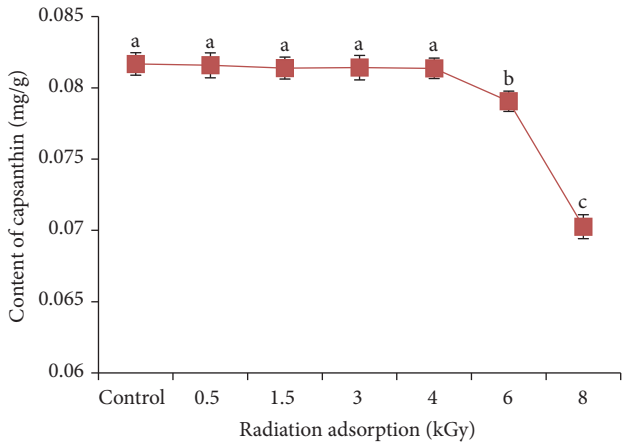

Figure 5: Effect of irradiation on capsanthin of SBJ. Values are represented as mean ± SD. Significance was tested by Duncan Multiple Range Test at $P < 0.05$, and values with the same superscript were found not significantly different from each other.

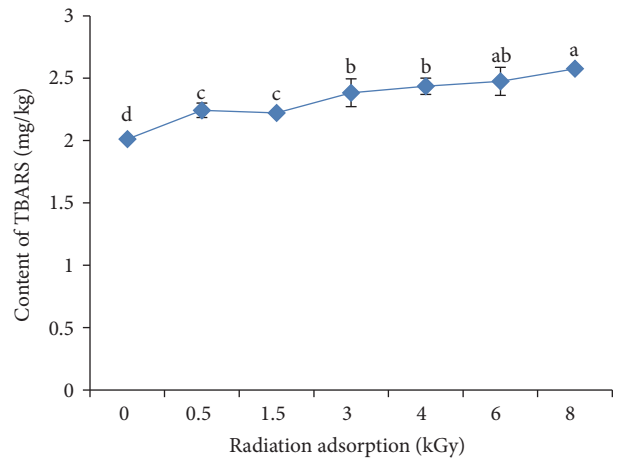

Figure 6: Effect of irradiation on lipid oxidation of SBJ. Values are represented as mean ± SD. Significance was tested by Duncan Multiple Range Test at $P < 0.05$, and values with the same superscript were found not significantly different from each other.

et al. [47] that low dose irradiation did not cause remarkable sensory changes for the majority of foods, but dosage higher than 5 kGy resulted in marked sensory quality change, such as foreign smell and getting brown.

Free radical reaction induced by irradiation might have resulted in the color change, lipid oxidation, and generation of off-odor [48]. Different explanations were provided for the development of off-odor. Gray et al. [49] thought lipid oxidation is one of the primary mechanisms of quality deterioration in meat products. Du et al. [19] thought both the breakdown products of lipid oxidation and sulfur-containing volatiles were responsible for irradiation odor of meat [50]. But Ahn et al. [51] thought the major contributor of off-odor in irradiated meat was not lipid oxidation, but radiolytic breakdown of sulfur-containing amino acids. As consumer's response to sensory changes of the irradiated meat and meat products are quite negative [19, 48], irradiation energy lower than 6 kGy should be used to sterilize SBJ.

3.5. Effect of Irradiation on Content of Capsanthin in SBJ. The content of capsanthin in SBJ was shown in Figure 5. The data (Figure 5) indicated that no significant ($P > 0.05$) change was observed as SBJ was treated with low dose radiation (0.5, 1.5, 3, and 4 kGy), but the content of capsanthin decreased significantly ($P < 0.05$) as SBJ was treated with doses of 6 kGy and 8 kGy. This result is consistent with the changes of a^* value of SBJ in Figure 1.

Capsanthin is the major pigment of red pepper. It makes the pepper powder look red and endowed SBJ with the beautiful red color. There are 11 unsaturated bonds in the capsanthin. Irradiation induced free radical reaction may result in the unsaturated bonds in the capsanthin being partially broken down [19, 48]. This may be the possible reason for the decrease of the capsanthin content and a^* of SBJ, as it was treated with 6 kGy and 8 kGy irradiation.

3.6. Effect of Irradiation on Lipid Oxidation of SBJ. TBARS is highly related to lipid oxidation, the amount of volatile substances, and the sensory quality of meat products [51]. Irradiation increases TBARS values in meats [39, 52]. Higher TBARS suggests more lipid oxidation happened, more volatile substances were produced, and the sensory quality of meat products decreased [53]. The TBARS of SBJ in Figure 6 indicated that TBARS of SBJ increased with the increase in irradiation dose. Similar phenomena happened as cooked ground beef was irradiated [54]. The increases of TBARS of SBJ in Figure 6 are consistent with the off-odor of SBJ as in Figure 4, and both of them increased as the irradiation energy was increased.

The chemical changes in irradiated meat are initiated by the free radicals [30, 46], which was generated by water molecules in muscle tissues or in meat products as irradiated [52]. Free radicals have strong oxidation ability and it can induce many autooxidizing and hydrolytic reactions [55]. Lipid is the most sensitive food component to free radicals [24, 56]. The increase of TBARS with irradiation dose increase in Figure 6 suggested more free radicals were produced. These free radicals attacked lipids, proteins, amino acids, and so forth [57] and thus resulted in undesired organoleptic changes and increase in the off-odor of meat products [51, 58]. Therefore, the results of irradiation on content of TBARS further supported the increase in off-odor of SBJ, decrease in the color preference and taste, and the reduction in content of the capsanthin with the increase of the irradiation dose.

3.7. Effect of Irradiation on Microorganism of SBJ. The changes of plate counts of aerobic bacteria and *Escherichia coli* in SBJ samples after irradiation were shown in Table 1. The data in Table 1 indicated that the plate counts of the aerobic bacteria and *Escherichia coli* decreased with the increase of irradiation dose. According to the hygienic standard of China for cooked meat products [59], the plate counts of aerobic bacteria decreased to less than 10^4 CFU/g, and *Escherichia coli* decreased to less than 30 MPN/100 g are safe to eat.

Table 1: Plate counts of aerobic bacteria and *Escherichia coli* in the SBJ after irradiation.

Irradiation dose (kGy)	0	0.5	1.5	3.0	4.0	6.0	8.0
Counts of aerobic bacteria (CFU/g)	2.8×10^5	5.1×10^4	8.0×10^3	4.9×10^2	77	<10	<10
Counts of *Escherichia coli* (MPN/100 g)	2400	300	<30	<30	<30	<30	<30

Therefore, irradiation dose of 4.0 kGy is enough for killing aerobic bacteria (77 CFU/g < 10^4 CFU/g) and *Escherichia coli* (<30 MPN/100 g) in the SBJ.

Given the purpose of irradiation is to pasteurize and improve the quality of the SBJ, combining the drip loss, the texture, and the sensory attributes of SBJ changed as the irradiation energy was increased. The irradiation energy should not be higher than 6 kGy as the irradiation method is used to sterilize SBJ.

4. Conclusions

The lightness, drip loss, and off-odor of SBJ increased while the hardness, chewiness, gumminess, sensory color, and taste of SBJ were decreased with the increase in irradiation dose. This tendency was more obvious as the irradiation dose was increased to 6 kGy and 8 kGy. The possible reason for these quality changes might be free radicals produced by irradiation. This speculation is supported by decrease of the content of capsanthin and increase of TBARS in SBJ with the increase in irradiation dose. The plate counts of SBJ indicated that irradiation dose of 4 kGy was enough for pasteurization of SBJ. Considering other quality changes, irradiation dose between 4 kGy and 6 kGy is recommended for treating SBJ.

Additional Points

Practical Application. SBJ is a typical snack meat product, which requires pasteurization to improve quality, shelf life, and food safety. Currently, sterilization of SBJ is performed using steam which is a cumbersome process with high energy usage. Irradiation is considered as the best method for control of pathogenic microorganisms in meat and meat products. To investigate feasibility of using irradiation to treat SBJ, it was treated with irradiation and the quality was analyzed. The results of irradiation on color, texture properties, drip loss, sensory attributes, and plate counts of SBJ set a good foundation for further application of the irradiation method in production of SBJ and other snack foods.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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