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Effects of cobalt-sourced γ-irradiation on the meat quality and storage stability of crayfishes *(Procambarus clarkii)*

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Abstract

This study aimed to explore the influences of cobalt-sourced irradiation on the meat quality and storage stability of *Procambarus clarkii*. Pieces of tail meat of *P. clarkii* were processed, boiled, and packed in transparentretort pouchs and then exposed to ^{60}Co-γ-ray (0, 1.25, 3.32, 5.30, and 7.24 kGy). Changes in meat indices such as pH, total plate count, and total volatile base-nitrogen (TVB-N), texture properties, were investigated. After irradiation at the optimum irradiation dose, crayfish meats was stored at 0, 4 and 8 °C respectively, samples were collected for determinations at 0, 3, 6, 9 and 12 days. With increased irradiation dose, the total plate count in meat significantly decreased, whereas TVB-N greatly increased ($P < 0.05$). The irradiation dose of 3.32 kGy can realize both sterilization effect and maintain the quality of crayfish meat to the maximum extent. Total plate count and TVB-N in crayfish meat slowly grew at a storage temperature of 0 °C, their contents reached or approached the edible threshold by 9th day of storage, thereby prolonging the shelf life to 9d. Research demonstrates that 3.32 kGy cobalt-sourced irradiation and 0 °C storage can provide some bacteriostasis to some extent and prolong the shelf life of boiled crayfish.

Keywords: *Procambarus clarkii*; cobalt-sourced γ-irradiation; storage; quality.

Practical Application: The ^{60}Co-γ irradiation technology and refrigeration treatment can effectively extend the shelf life of crayfish products and improve the technical problems of muscle texture property retention during crayfish product processing.

1 Introduction

Crayfish (*Procambarus clarkii*), also called freshwater crayfish, belongs to the *Cherax, Cambaridae, Decapoda, Crustacea*. It originates from Mexico and some regions of the USA. Due to the various feeding habits, quick growth, and strong adaptation of crayfish, it can easily develop advantages in the local ecological environment (Cronin, 1998; Cruz & Rebelo, 2006). In 2020, the global production of crayfish reached 2.469 million tonnes (t), accounting for 22% of the total production of crustaceans in Food and Agriculture Organization (2022). At present, crayfish is an important freshwater economic prawn category in China. According to the estimate of Report on the Development of Chinese Crayfish Industry in 2021, despite the adverse impact of COVID-19 epidemic on catering industry, the total output value of crayfish in China in 2020 still reached 344.85 billion yuan, showing a year-on-year growth of 9.11% in crayfish processing industry (National Fisheries Technology Extension Center & China Society of Fisheries, 2020). Crayfish has become one of the most extensively consumed aquatic products in China and even in the world (Annamalai et al., 2015).

Crayfish is highly appreciated by consumers for its rich nutrients and delicious taste. However, it can be easily polluted by exogenous microorganisms, thereby resulting in high vulnerability to decreased freshness, decreased nutritive values, and even rotting phenomena (Annamalai et al., 2015). Due to the shell of crayfish, existing processing techniques such as pasteurization and high-temperature sterilization are disadvantageous because of their high energy consumption, incomplete sterilization, and enzyme deactivation, thereby inducing instability of shelf life and inflicting damage to nutrients and sensory quality of products (Maherani et al., 2016; Moreno-Vilet et al., 2018). As policy makers propose increasing requirements for food safety and quality, the crayfish industry urgently needs a processing mode with low energy consumption, high efficiency, thorough sterilization and deactivation, and small influences on product quality.

Non-thermal treatment is a new technology that inactivates microorganisms under processing conditions such as ionizing radiation, pulsed electric fields, ultraviolet light, cold plasma, and high-intensity ultrasound to maintain product nutrition and quality and extend product shelf life (Santhirasegaram et al., 2015; Wei et al., 2022). Irradiation is an efficient and low-carbon non-thermal processing technique conducive to strengthening food hygiene and safety and prolonging the shelf life of food. The nutrient loss caused by irradiation is similar only to the nutrient loss caused by boiling or freezing (Ravindran & Jaiswal, 2019). One of the key technologies in irradiation lies in the determination of irradiation dose. An insufficient dose leads to incomplete sterilization, whereas an excessive dose negatively influences the sensory and physicochemical indices of products. The irradiation sources currently approved for the food industry include the electropmagnetism (γ) rays gained

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from the radiation form of cobalt (^{60}Co) or cesium (^{137}Cs), X-ray, and electron-beam radiation (Bouzarjomehri et al., 2020). Among them, Co-sourced γ-rays have very high penetrability and can directly process agricultural and sideline products in packages (Bisht et al., 2021). They can effectively inactivate harmful putrefying microorganisms without increasing the food-processing temperature.

Different food raw materials have to adopt different levels of irradiation dose to retain freshness (Prakash, 2016; Rahman et al., 2018). A dose of 2-10 kGy is recommended for aquatic products and meat products to ensure the shelf life of the food and not to affect its nutritional properties (Yao et al., 2022). Badr (2012) studiedγ-ray irradiation and found that under a dose of 3 kGy, the edible safety of smoked salmon significantly increases without obvious influences on moisture content, salt, pH, total volatile base-nitrogen (TVB-N), and trimethylamine. Moini et al. (2009) pointed out that low-dose irradiation (3 kGy) can control microbiological indicators and the safety biochemical index within a 4-week freezing-storage period without influencing the quality and acceptability of products. Özden et al. (2007) showed that during storage at 4 °C the microorganism quantity of sea bass (*Dicentrarchus labrax*) samples before γ-irradiation is significantly higher than that in sea bass samples after γ-irradiation (2.5 kGy and 5 kGy). Previous studies have focused on the irradiation of fishes, studies on the effect of γ-ray irradiation on Crustacea are lacking. Due to the existence of shells, Crustacea poses great challenges to sterilization, freshness retaining, and quality control.

In the study, ^{60}Co-γ-ray irradiation at room temperature was applied to boiled crayfish. The microorganism and texture properties of crayfish meat were investigated. Attention was paid to the influences of irradiation dose on the total plate count, pH, TVB-N, and texture properties of crayfish meat, as well as the changes in storage characteristics. On this basis, the optimal irradiation dose, storage temperature, and storage time were determined. This study provided data to support the promotion of irradiation technology in the crayfish processing industry.

2 Materials and methods

2.1 Materials

Crayfish (body length of about 12-13 cm, and weight ranging within 28-30 g; n = 500) samples were purchased from local markets in Hongshan District, Wuhan City, Hubei Province, China. The cleaned crayfish was steamed for 5 min. The heads and shells were eliminated, and the tail meat was collected and rinsed for later use. Hexane (chromatographic purity) was provided by Meker, Germany. Bovine serum albumin (analytical purity) was provided by Shanghai Yuanye Biotechnology Co., Ltd. Tryptone, yeast extract and agar were provided by Beijing Double Spin Microbiological Medium Products Factory. All reagents were of analytical grade.

2.2 Irradiation treatment of crayfish

The boiled crayfish meats were kept in retort pouchs. The sealed bags were placed in foam boxes that had gel ice bags in advance to avoid temperature rise during irradiation. Samples were sent to the Hubei Irradiation Experimental Center and exposed to ^{60}Co-γ-ray. The Co source activity was 1.21×10^{16} Bq, and the range of the unit adsorbed dose was 2.23-31.39 Gy/min.The irradiation dose of the pre-experiment was set as 0, 1, 3, 5, 7 and 9 kGy. According to the pre-experiment results, the 9 kGy group with severe juice loss was excluded, finally irradiation doses of 0, 1, 3, 5, and 7 kGy were processed and then samples were frozen. Subsequently, physicochemical and microorganism tests of crayfish meats processed under different irradiation doses were performed. The practical absorption dose of samples were calibrated using silver dichromate dosimeters (glass ampoule dosimeter, where the low-dose range contained 0.35 mmol/L silver dichromate and the high-dose range contained 2.5 mmol/L silver dichromate). The dosimeter was kept at room temperature and then exposed to irradiation with samples before sending to the Hubei Irradiation Engineering Center for detection. The practical adsorption doses were 0, 1.25, 3.32, 5.30, and 7.24 kGy.

2.3 Crayfish storage at different temperatures

According to test results of total plate count and quality indices of crayfish meat, the most suitable dose was selected for the storage experiment. Every 30 g of crayfish meat after processing under the optimal irradiation dose were placed in a retort bag, and all bags were stored at 0 °C, 4 °C, and 8 °C. The samples without irradiation processing were selected as blank samples. Three parallel samples of each sample were stored for a total of 12 days, and samples were collected every 3 d to determine their pH, TVB-N and texture indices.

2.4 Determination of physicochemical properties of irradiated crayfish meat

Measurement of pH

We collected 5 g of crayfish meat (n = 100) and crushed it, after which 45 mL of deionized water was added. The mixture was placed in a high-speed disperser for homogenization (Model: XHF-DY, Ningbo Xinzhi Biotechnology Co., Ltd.). After centrifugation, the supernatant was collected and tested with a calibrated pH meter (Model: PB-10, Sartorius Instruments Ltd. Germany). Each treatment was tested three times, and the mean was recorded.

Determination of TVB-N

A total of 5 g of crayfish meat (n = 100) was collected and completely ground with 50 mL of deionized water. TVB-N was tested by the method of Qiao et al. (2017) with slight modifications. Data are expressed as mean ± s.d. (n = 3).

Measurement of total number of colonies and D_{10} value

The D_{10} value was defined as the irradiation dose for decreasing 1 $\log_{10}$ or 90% of microorganism (Hossain et al., 2014). The D value refers to the irradiation dose needed to decrease the total plate count of samples to N ≤ 10 CFU/g, and it is an important reference indicator that determines the dose for sterilization. With reference to Boinapally's methods, it was slightly adjusted to test the total plate count (Boinapally & Jiang, 2007). The linear-regression equation between total plate count (logCFU/g) and irradiation dose was plotted. The D_{10} value was determined

according to the reciprocal of the straight slope, and it was then brought into the formula to calculate the D value (Equation 1).

$$D = \lg \frac{N_0}{N} \times D_{10} \quad (1)$$

where D is the irradiation dose, kGy; N_0 is the total number of bacterial colonies before irradiation, CFU/g; N is the total number of residual bacterial colonies remaining after irradiation, CFU/g.

Texture analysis

Crayfish meats ($n = 200$) with similar shapes and weights were selected to test hardness, springiness, cohesiveness, and chewiness in sample properties by using a TA-XT Plus property tester (Stable Micro Systems, UK). A P/0.5 cylindrical probe was selected. Speeds before, during, and after the test were 2, 3, 5 mm/s, respectively. The test interval was set at 5 s, and the test deformation was 50% (Martinez et al., 2004). Each sample had three parallel samples, and each parallel sample was tested five times.

2.5 Statistical analysis

Results are expressed as the mean ± standard deviation. Statistical analyses of pH, TVB-N, total plate count, and texture data were performed using the statistical software SPSS 20.0 (IBM, Chicago, USA). Microbial count was transformed to logCFU/g, and pair comparison of sample means was realized by ANOVA. Each group of data was analyzed at least three times. Differences at the level of $P < 0.05$ were viewed as statistically significant.

3 Results and discussion

3.1 Total plate count, pH, and TVB-N of crayfish meat under different irradiation doses

Table 1 shows that with increased irradiation dose, total plate count in crayfish meat significantly decreased ($P < 0.05$).

Table 1. The total plate count, pH, and TVB-N of crayfish meat under different irradiation doses.

Irradiation doses (kGy)	Total plate count (logCFU/g)	TVB-N (mg/100 g)	pH
0	2.84 ± 0.01^{a}	2.80 ± 0.03^{e}	7.60 ± 0.02^{d}
1.25	2.49 ± 0.01^{b}	3.71 ± 0.02^{d}	7.67 ± 0.04^{c}
3.32	1.64 ± 0.03^{c}	4.10 ± 0.04^{c}	7.75 ± 0.01^{ab}
5.30	1.45 ± 0.04^{d}	4.66 ± 0.02^{b}	7.71 ± 0.02^{bc}
7.24	<1	4.94 ± 0.03^{a}	7.78 ± 0.03^{a}

Different letters in the same column indicate significant differences between treatment at $P < 0.05$. Values represent means ± standard deviation of three replicates.

Before irradiation, the initial total plate count of samples was 2.84 ± 0.01 logCFU/g, but it reached less than 1 logCFU/g with increased irradiation dose to 7.24 kGy. The reason may be the direct damage inflicted by the high-energy rays produced by irradiation to microbial nucleic acids, as well as damages to enzymes and organelles caused by water irradiation-induced decomposition products (Al-Masri & Al-Bachir, 2007). From the linear-regression equation ($y = -0.3664x+2.8815$, $R^2 = 0.991$), we calculated that D_{10} = 2.73 kGy. It was calculated that the theoretical sterilization dose D was 4.97 kGy when the total plate count was decreased to10 CFU/g. In other words, the total plate count of boiled crayfish meat met the standard (Hossain et al., 2014) when the ^{60}Co-γ-ray irradiation dose exceeded 4.97 kGy, which was close to 5.30 kGy in the test results. According to the food pathogenic-bacteria limit in GB 29921-2013, the upper limit of total plate count is 3 logCFU/g (China, 2021), and samples loose edible values once this critical value is exceeded.

As shown in Table 1, TVB-N content in crayfish meat before irradiation was about 2.80 mg/100 g. With increased irradiation dose, TVB-N in samples significantly increased ($P < 0.05$). Compared with the control group, the pH of boiled crayfish meat after irradiation significantly increased ($P < 0.05$). However, insignificant differences in pH values existed among crayfish meats under different irradiation doses ($P > 0.05$). pH is one of most important indices to measure the freshness of prawns (Annamalai et al., 2018), and pH of boiled shrimp is weak alkaline (Zhang et al., 2011). Crayfish meat contains water, and the e^{-aq}, H•, and OH• formed by water after γ-radiation can accelerate the decomposition of proteins in crayfish meat, thereby changing the protein structures, including changes in deoxygenation, decarboxylation, breakage of disulfide bonds, and sulfydryl oxidation (Meinlschmidt et al., 2016). All of these phenomena may explain the increased TVB-N and pH of crayfish meat after irradiation.

3.2 Texture properties of crayfish meat under different irradiation doses

Table 2 shows that a higher irradiation dose resulted in poorer texture properties of crayfish meat. Compared with the control group (0 kGy), the hardness and chewiness of crayfish meat after irradiation were significantly higher ($P < 0.05$). With increased irradiation dose, springiness and cohesiveness presented the opposite variation trend. Irradiation doses ranging between 3.32 and 7.24 kGy had no significant influences on the springiness and chewiness of samples. This finding was similar to the research conclusions of Lv et al. (2018) concerning the influences of irradiation on the springiness of *Tegillarca granosa* meat. Protein contains some hydrophobic amino acid residues

Table 2. The texture properties of crayfish meat under different irradiation doses.

Irradiation doses (kGy)	Hardness	Cohesiveness	Springiness	Chewiness
0	334.82 ± 43.58^{c}	3.43 ± 3.48^{a}	94.39 ± 2.92^{a}	252.73 ± 66.43^{b}
1.25	1153.06 ± 49.34^{b}	-2.90 ± 4.93^{a}	77.23 ± 2.61^{b}	574.47 ± 30.96^{a}
3.32	1109.90 ± 28.45^{b}	-76.50 ± 0.52^{c}	70.26 ± 3.95^{c}	591.49 ± 29.95^{a}
5.30	1332.75 ± 44.70^{a}	-87.06 ± 7.43^{d}	66.76 ± 1.14^{c}	644.27 ± 53.47^{a}
7.24	1364.58 ± 33.29^{a}	-63.48 ± 5.44^{b}	71.67 ± 3.21^{c}	608.19 ± 57.61^{a}

Different letters in the same column indicate significant differences between treatment at $P < 0.05$. Values represent means ± standard deviation of three replicates.

that carry benzene rings. These residues are usually buried inside protein structures, and the free radicals produced by the water radiolysis of crayfish meat can lead to comformational changes of proteins and cause hydrophobic-residue exposure. As a result, the surface hydrophobicity of proteins increased, whereas the water-binding capacity of proteins declined, changing the texture accordingly (Shi et al., 2015). Moreover, it was found that with increased irradiation dose to 5.3 kGy and higher, crayfish meat developed an irradiation-induced odor, consistent with the experimental results of Lv et al. (2018). Accordingly, an irradiation dose of 3.32 kGy was used for the subsequent storage experiment.

3.3 Total plate count of crayfish meat during storage

Table 3 shows that with increased temperature and storage time, the total plate count of crayfish meat after radiation continuously increased, and significant differences existed among different groups ($P < 0.05$). Research has demonstrated that active particles produced by applying high-energy ray onto water molecules could indirectly damage the genetic materials of microorganism and effectively inhibit most food-borne pathogens and rotting biology (Kalaiselvan et al., 2018; Li et al., 2013; Munir & Federighi, 2020). With increased storage time, the residual microorganism began to reproduce in the large scale, and the total plate count quickly increased. At 4 °C and 8 °C the total plate count began to exceed the edible range since the 6 d. At 0 °C the total plate count slowly grew, it reached 3.19 ± 0.15 logCFU/g at 12 d, exceeding the up limit of 3 logCFU/g, and the crayfish meat can still be eaten in 9 d. This finding indicated that microfreezing storage can decelerate the reproduction speed of microorganism, consistent with the decelerated deterioration of ice stored croaker (*Johnius dussumieri*) fish and chill stored indian mackerel in the study of Annamalai et al. (2018) and Viji et al. (2016).

3.4 pH of crayfish meat in the storage process

Table 4 shows that throughout the entire storage period, the pH of crayfish meat after radiation generally increased continuously. The pH of crayfish meat at 4 and 8 °C increased more compared with that under 0 °C. The increased pH during storage was attributed to microbial metabolism. Due to microbial growth, the alkali compound release from muscular protein and nonprotein nitrogen-containing compounds was accelerated, thereby continuously accumulating alkali compounds (Binsi et al., 2014; Tian et al., 2022).

3.5 TVB-N in crayfish meat during storage

Variations in TVB-N in crayfish meat during storage are shown in Table 5. With increased storage time, the TVB-N of different groups significantly increased ($P < 0.05$). However, its growth was slow in the early stage but quick in the late stage. This finding was due to the ability of radiation to inhibit bacterial growth and reproduction, as well as to inhibit enzyme effect. Thus the protein decomposition to the volatile nitrogen-containing substances induced by bacteria decelerated in the early stage. As storage continued, the amino acids decomposed through enzymes became nutrient supply by microorganisms, and they reproduced in the large scale. Meanwhile, proteases that can decompose the muscle protein of crayfish were secreted to further promote the deamination and decarboxylic reaction of amino acids in crayfish meat, thereby producing ammonia, amine, and other alkaline nitrogen-containing substances. Accordingly, TVB-N content continued to increase (Torusdağ et al., 2022; Kuswandi et al., 2011). With increased temperature, TVB-N content significantly increased ($P < 0.05$). Shukla et al. (2015) suggested that the maximum limit of TVB-N should not exceed 20 mg/mg. At 6 d, the TVB-N content in irradiation samples was exceeded the edible critical value at 4 °C and 8 °C, and was significantly different from the TVB-N content at 0 °C ($P < 0.05$). This result was due to the significant influence of temperature on the enzyme activity and vital activity of microorganism. Low temperatures can decrease microbial reproduction or relieve

Table 4. The pH of irraditated crayfish meat during storage at different temperatures.

Storage time (d)	0 °C	4 °C	8 °C
0	7.47 ± 0.01^{d}	7.47 ± 0.01^{e}	7.47 ± 0.01^{e}
3	7.46 ± 0.01^{dC}	7.58 ± 0.01^{dB}	7.73 ± 0.01^{dA}
6	7.85 ± 0.01^{cC}	7.96 ± 0.01^{cB}	8.17 ± 0.005^{cA}
9	8.02 ± 0.01^{bC}	8.36 ± 0.01^{bB}	8.58 ± 0.01^{bA}
12	8.23 ± 0.01^{aC}	8.84 ± 0.01^{aB}	8.92 ± 0.01^{aA}

Different capital letters in the same line indicate significant differences between temperature groups ($P < 0.05$). Different lowercase letters in the same column indicate significant differences between time groups ($P < 0.05$). Values represent means ± standard deviation of three replicates.

Table 3. The total plate count of irraditated crayfish meat during storage at different temperatures. (logCFU/g).

Storage time (d)	0 °C	4 °C	8 °C
0	1.93 ± 0.11^{d}	1.93 ± 0.11^{e}	1.93 ± 0.11^{e}
3	2.25 ± 0.18^{cB}	$2.53 \pm 0.16d^{AB}$	2.78 ± 0.19^{dA}
6	2.58 ± 0.19^{bC}	3.05 ± 0.12^{cB}	3.53 ± 0.16^{cA}
9	2.97 ± 0.11^{aC}	3.68 ± 0.11^{bB}	4.04 ± 0.16^{bA}
12	3.19 ± 0.15^{aC}	3.99 ± 0.16^{aB}	4.38 ± 0.15^{aA}

Different capital letters in the same line indicate significant differences between temperature groups ($P < 0.05$). Different lowercase letters in the same column indicate significant differences between time groups ($P < 0.05$). Values represent means ± standard deviation of three replicates.

Table 5. The TVB-N of irraditated crayfish meat during storage at different temperatures.

Storage time (d)	0 °C	4 °C	8 °C
0	3.13 ± 0.503^{e}	3.13 ± 0.503^{e}	3.13 ± 0.503^{e}
3	6.27 ± 0.188^{dC}	11.58 ± 0.650^{dB}	18.25 ± 1.811^{dA}
6	13.10 ± 0.496^{cC}	20.95 ± 0.325^{cB}	32.15 ± 0.495^{cA}
9	20.71 ± 0.650^{bC}	31.78 ± 0.325^{bB}	42.27 ± 0.325^{bA}
12	30.75 ± 0.324^{aC}	43.25 ± 0.649^{aB}	56.17 ± 0.325^{aA}

Different capital letters in the same line indicate significant differences between temperature groups ($P < 0.05$). Different lowercase letters in the same column indicate significant differences between time groups ($P < 0.05$). Values represent means ± standard deviation of three replicates.

Table 6. The texture properties of irraditated crayfish meat during storage at different temperatures.

Storage time (d)		0 °C	4 °C	8 °C
Hardness	0	1324.48 ± 54.80^{a}	1324.48 ± 54.80^{a}	1324.48 ± 54.80^{a}
	3	1177.36 ± 28.36^{bA}	1165.92 ± 69.32^{bA}	1145.41 ± 49.90^{bA}
	6	1091.61 ± 80.20^{bA}	994.26 ± 67.32^{cA}	1039.58 ± 81.74^{bA}
	9	744.26 ± 73.13^{dA}	845.99 ± 93.20^{dA}	809.91 ± 40.51^{cA}
	12	905.97 ± 70.68^{cA}	917.06 ± 87.44^{cdA}	1058.16 ± 85.16^{bA}
Springiness	0	72.32 ± 2.68^{ab}	72.32 ± 2.68^{b}	72.32 ± 2.68^{b}
	3	74.25 ± 1.60^{aC}	77.04 ± 1.17^{bB}	81.01 ± 0.86^{abA}
	6	76.36 ± 1.02^{aA}	77.92 ± 4.34^{bA}	75.91 ± 0.86^{bA}
	9	67.52 ± 5.53^{bB}	80.88 ± 2.58^{bA}	87.84 ± 11.67^{aA}
	12	72.47 ± 4.68^{abB}	97.04 ± 3.45^{bA}	78.46 ± 2.43^{abB}
Chewiness	0	712.26 ± 48.73^{a}	712.26 ± 48.73a	712.26 ± 48.73^{a}
	3	556.18 ± 26.26^{bA}	600.14 ± 45.98^{bA}	577.81 ± 64.49^{bcA}
	6	510.27 ± 31.66^{bA}	536.46 ± 12.97^{bA}	556.72 ± 52.48^{cdA}
	9	509.90 ± 80.63^{bA}	465.63 ± 36.71^{cA}	454.37 ± 61.05^{dA}
	12	437.67 ± 29.84^{cA}	434.34 ± 49.07^{cA}	402.95 ± 73.60^{abA}

Different capital letters in the same line indicate significant differences between temperature groups ($P < 0.05$). Different lowercase letters in the same columns indicate significant differences between time groups ($P < 0.05$). Values represent means ± standard deviation of three replicates.

the bacterium-induced oxidization of nonprotein nitrogen compounds (Zhang et al., 2011, 2012).

3.6 Texture indices of crayfish meat during storage

Texture is usually correlated closely with dehydration and muscle-protein degradation during the thermal process. Generally, consumers prefer crayfish meat with appropriate hardness and springiness. Table 6 shows that with increased storage time, the hardness of irradiation samples initially decreased and then increased, but it generally declined significantly ($P < 0.05$). Chewiness decreased dramatically ($P < 0.05$) comparing with the unirradiation samples, whereas springiness presented an irregular variation. The reduction in hardness may be related to the gradual loss of water in crayfish meat and the reduction in water-binding capacity during storage (Binsi et al., 2014). It also may be caused by the weakening of muscle connective tissues in response to the degradation of proteins in crayfish meat by the abundant endogenous enzymes and exogenous proteases produced by microorganisms (Annamalai et al., 2018). For storage time extension, the chewiness of irradiated samples significantly decreased ($P < 0.05$). One reason may be the decrease in protein gel-network structural strength because of the continued slow degradation of fibrillin and collagen fibrin by endogenous and exogenous proteases (Viji et al., 2015). At 9 d, the chewiness of samples decreased with increased temperature. This finding might be due to the ability of low temperature to inhibit myofibril degradation to some extent.

4 Conclusions

Crayfish meat was irradiated by ^{60}Co-γ-rays. Within the irradiation range of 0–7.24 kGy, the total plate count, cohesiveness, and springiness of crayfish meat were negatively correlated with irradiation dose. By contrast, hardness, chewiness, pH, and TVB-N were positively correlated. Irradiation can effectively kill rotten microorganism in crayfish meat. A higher irradiation dose corresponded with better sterilization effect. When the irradiation dose reached 7.24 kGy, cohesiveness and springiness decreased, whereas hardness and chewiness increased. Crayfish meat had relatively poor texture. An irradiation dose of 3.32 kGy can realize sterilization effect and maintain the edible property to the maximum extent, therefore 3.32 kGy irradiation was selected for the 12 d storage experiment. Storage experiment revealed that the total plate count, pH, and TVB-N of crayfish meat increased with time. Among different temperature groups, pH and texture properties slightly changed. Moreover, the total plate count and TVB-N of the 0 °C group grew more slowly than those of the 4 °C and 8 °C groups, and the content does not exceed the edible limit within 9 d of storage. The shelf life of the 0 °C group could be increased to 9 d, indicating that low temperature decelerated the reproduction speed of microorganisms. Overall, crayfish meat treated with an irradiation dose of 3.32 kGy and 0 °C showed the best storage effect. In other words, irradiation and microfreezing storage can effectively prolong the shelf life and maintain the texture properties of crayfish meat products.

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