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Research Article

Application of Gelatin Incorporated with Red Pitaya Peel Methanol Extract as Edible Coating for Quality Enhancement of Crayfish (*Procambarus clarkii*) during Refrigerated Storage

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China is one of the largest producers of red pitaya in the world and responsible for disposal of the huge amount of peel generated as a waste. The objective of this research was to evaluate the effect of the addition of red pitaya peel extract (RPPE, 1.0%, 2.0%, or 3.0% (w/v)) and 0.1% ε-polylysine (ε-PL) to a fish gelatin edible coating on the preservation of deshelled crayfish (*Procambarus clarkii*) during refrigerated storage. The physicochemical and water migration of the samples were determined during 8-day storage. Deshelled crayfish packaged in edible coatings exhibited significantly ($p < 0.05$) lower values for total volatile basic nitrogen (TVB-N), *K* value maintenance, and free amino acids (FAAs). This study shows that application of an edible coating incorporated with RPPE and ε-PL is an effective strategy in retarding the quality deterioration in deshelled crayfish during storage.

1. Introduction

Crayfish (*Procambarus clarkii*), with high protein and low fat, is a freshwater economic shrimp in China [1]. In 2016, the total crayfish output was about 90 million tons. Crayfish are usually shucked so that they can be sold as ready-made raw meat, which is more acceptable to consumers and meets the needs of the freshwater product industry [2]. However, crayfish are highly susceptible to microbial infection after shucking and they are not easy to preserve [3]. Free amino acids and other soluble non-nitrogenous substances in crayfish serve as digestible nutrients for microbial growth [4], and this causes a loss in freshness and lowers the quality of the product, causing a market loss of crayfish. Therefore, the development of storage methods that reduce or delay the loss of freshness is important to the crayfish industry.

Pitaya, belonging to Cactaceae family, is a native fruit from Mexico and Central and South America [5, 6]. Red pitaya peel is considered a waste of the processing and represents 33% of the fruit total weight [7]. Red pitaya peel (RPP) is abundant in antioxidant compounds and has an important antioxidant potential [8], which could ensure the chemical stability of deshelled crayfish during refrigerated storage. Pitaya peel is a residue of fruit consumption and processing [9]. In an era of great concern with environmental problems, food by-product valorization and application of green extraction processes have gained much attention [10]. Extracting the active ingredient from the peel can improve the utilization of the peel. Meanwhile, peel extracts are commonly used as biological preservatives in many food processes, especially in the aquatic product, to prolong shelf life including essential oils from tangerine peels and mango peel extracts and

polyphenols from apple peels [6, 11, 12]. Edible coating can be used to protect phenolic compounds from oxidation by external factors such as the presence of light, oxygen, metal ions, pH, and high temperatures [13] and provide fresh food protection to prevent quality loss and weight loss. Several researchers have applied it to the storage of aquatic products [14–16].

In this study, we investigated the effect of the addition and the level (1.0%, 2.0%, and 3.0% (w/v)) of red pitaya peel extract (RPPE) combined with 0.1% ε-PL on the physicochemical and water migration of deshelled crayfish stored at 4°C under aerobic condition.

2. Materials and Methods

2.1. Preparation of RPPE. Fresh red pitaya fruits were obtained from the producer in Zhanjiang, China, and the peel was manually separated, lyophilized for 48 h, and milled in a commercial blender (WBL1022S, Guangdong Midea Electric Appliances Co., Ltd, China). The fine powder sifted through a 40-mesh sieve was collected and stored in an amber flask. The powder (25.0 g) was mixed with 200 mL of methanol and water (80 : 20, v/v) solution and then transferred to an ultrasonic extractor (KQ-100DE, Kunshan Ultrasound Instrument Co., Jiangsu, China) at a power of 240 W for 30 min. After extraction, the solution was centrifuged at 3100 × g for 15 min at 4°C, and the supernatant was transferred to an amber flask. The extract was concentrated using a rotary evaporator (RE-5299, Shanghai Yarong Biochemical Instrument Factory, Shanghai, China) at 50 rpm and 40°C under vacuum to remove methanol and then freeze-dried. The freeze-dried RPPE powder samples were stored at 4°C in the dark [8].

2.2. Determination of Polyphenols of RPPE

2.2.1. Total Polyphenolic Content. The total polyphenolic content was determined by the Folin–Ciocalteu colorimetric method based on oxidation/reduction reactions of phenols, and the results were expressed as milligram gallic acid equivalent per gram dry weight (mg·GAE/g·dw) of RPPE powder [17].

2.2.2. Determination of Betacyanin Content. The absorbance of betacyanin was determined using the method described by de Mello et al. [18]. Quantification of betalains was calculated by the following equation:

$$\text{betacyanin content}\left(\frac{\text{mg}}{100\,\text{g}}\right) = \frac{A \times \text{DF} \times \text{MW} \times V \times 100}{\varepsilon \times L \times W}, \quad (1)$$

where A is the absorption value at 538 nm; DF is the dilution factor; MW is the molecular weight of betanin (550 g/mol); V is the pigment solution volume (mL); ε is the molar extinction coefficients of betanin (60,000 $\text{L}\cdot\text{mol}^{-1}\cdot\text{cm}^{-1}$); L is the path length of the cuvette; and W is the weight of pigment powder (g).

2.3. Extraction of Salmon Skin Gelatin. This method described by Tkaczewska et al. [19] was used with some modifications. The salmon skins were cut into small pieces (5 × 5 cm) and poured into water to remove adhesive impurities and soaked in 0.05 $\text{mol}\cdot\text{L}^{-1}$ sodium hydroxide for 2 h at a sample/alkali solution ratio of 1 : 6 (w/v). Then, skins were washed with distilled water at 4°C until neutral to remove the remaining alkali, soaked in 0.05 $\text{mol}\cdot\text{L}^{-1}$ acetic acid for 2 h at a sample/acid solution ratio of 1 : 6 (w/v), and then also washed to neutrality at 4°C. The pretreated skins were extracted with distilled water at 50°C for 6 h, and the mixture was filtered and then lyophilized to obtain the gelatin sample.

2.4. Preparation of Preservative Solutions. Gelatin solution (1.2%, (w/v)) was prepared by dispersing gelatin in distilled water at 60°C and stirring for 3 h. After dissolved completely, the solution was filtered with cheesecloth and then 0.1% ε-PL was added and the mixture was homogenized at 30k rpm for 60 s. All the edible coating solutions (G: gelatin solution containing 0.1% (w/v) ε-PL; G-1% RPPE: gelatin solution containing 0.1% (w/v) ε-PL and 1% RPPE; G-2% RPPE: gelatin solution containing 0.1% (w/v) ε-PL and 2% RPPE; G-3% RPPE: gelatin solution containing 0.1% (w/v) ε-PL and 3% RPPE) were prepared and adjusted to pH 7.0. Finally, a vacuum pump was applied to remove air bubbles from the solutions.

2.5. Determination of Antioxidant Activity of Preservative Solutions. The antiradical activities of preservative solutions were determined using the stable radical DPPH (2,2 diphenyl-1-picrylhydrazyl) according to Mansour et al. [20]. The ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)) radical-scavenging activity was conducted using the method described by Zhou et al. [21]. The antioxidant capacity of the sample was expressed in terms of the molar concentration of the standard.

2.6. Preparation and Treatment of Crayfish Samples. Fresh red swamp crayfish (*Procambarus clarkii*) in the same size (9.5 ± 0.3 cm) were purchased from Luchaogang fresh market, Shanghai. Crayfish were transported in a foam-padded box with ice to the lab in 2 hours. Then, the crayfish were cleaned with ice water, the heads and shells were removed, and then they were washed with ice distilled water. The deshelled crayfish were randomly assigned to the five following batches: (1) uncoated (control, CK); (2) treated with gelatin solution containing 0.1% (w/v) ε-PL without RPPE (T0); (3) treated with gelatin solution containing 0.1% (w/v) ε-PL with 1% RPPE (T1); (4) treated with gelatin solution containing 0.1% (w/v) ε-PL with 2% RPPE (T2); (5) treated with gelatin solution containing 0.1% (w/v) ε-PL with 3% RPPE (T3). The deshelled crayfish were individually coated by immersing in the edible coating for 60 s (ratio of coating solution to crayfish, 5 : 1), and then, the coated samples were removed and allowed to drain at 4°C for 20 min to form the edible coatings. The control samples were dipped in sterile purified water as other coating solutions for 1 min and then drained at 4°C. The

treated crayfish samples were then packed in polyethylene bags and stored at 4 ± 0.5°C for 8 days. The experimental design is shown in Figure 1. Physicochemical and water migration analyses were performed at 0, 2, 4, 6, 7, and 8 days of storage to study the progress of deterioration.

2.7. Physicochemical Analysis

2.7.1. pH and Conductivity Measurement. The pH measurement and conductivity were determined according to Kim et al. [22] using the pH meter (PB-10; Sartorius, Germany) and conductivity meter (FE30; Mettler Toledo, Shanghai, China).

2.7.2. K Value. The *K* value was determined according to Fang et al. [23].

2.7.3. Determination of Total Volatile Basic Nitrogen (TVB-N). The TVB-N values were determined according to Shi et al. [24], and the TVB-N values of crayfish samples were expressed in mg N/100 g.

2.7.4. Determination of Free Amino Acids (FAAs). The FAAs were measured by the method according to Yu et al. [25] using the automatic amino acid analyzer (L 8800; Hitachi Ltd, Japan).

2.8. LF NMR Analysis. LF NMR analysis was performed according to the method of Li et al. [26]. Portions of 0.5 × 0.5 × 0.2 cm (about 1 g) were cut from the dorsal part of crayfish and sealed with polyethylene films. The samples were placed in NMR tubes (70 mm diameter). T_2 measurements were recorded on a LF NMR analyzer (MesoMR23-060H.I, Newmai co., Ltd., CA) with a proton resonance frequency of 20 MHz, and the primary parameters were as follows: SW = 100 kHz, RFD = 0.08, NS = 4, $P1$ = 18 μs, $P2$ = 36 μs, RG1 = 20 dB, DRG1 = 6 dB, PRG = 0, delay DL1 = 0.2 ms, and TW = 2000 ms. Longitudinal relaxation T_1 was measured by using the inversion-recovery sequence by the following parameters: $P1$ = 18 μs, $P2$ = 36 μs, SW = 200 KHz, RFD = 0.020 ms, RG1 = 20 dB, DRG1 = 1, NS = 4, TW = 5,000 ms, PRG = 0, NTI = 20, and DL1 = 0.2 ms.

2.9. SEM. Pieces of 3.0 × 5.0 mm muscle tissue were cut from the sample, fixed with 2.5% glutaraldehyde for 2 h at 4°C and then washed with phosphate buffer (pH 7.2) three times. Gradient elution with 50, 70, 80, 90, 95, and 100% ethanol was performed for 15 min, respectively. Microstructure observations of surface were carried out using a SEM S-3400N (Hitachi, Japan).

2.10. Statistical Analysis. The one-way ANOVA procedure followed by Duncan's multiple range tests was adopted to determine the significant difference ($p < 0.05$) among treatment means, and the results were expressed as means ± SD.

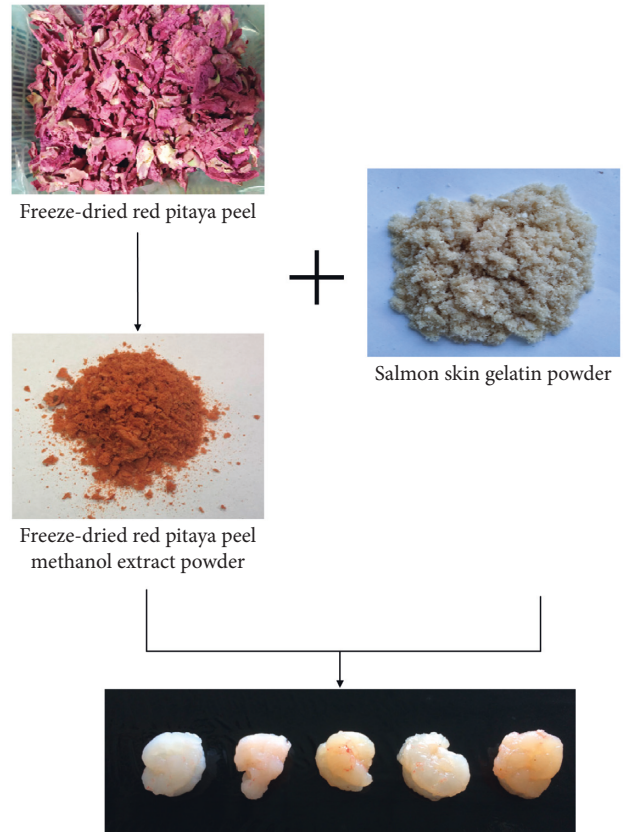

Figure 1: Application of gelatin-based edible coating containing red pitaya peel methanol extract on deshelled crayfish at day 0.

3. Results and Discussion

3.1. Antioxidant Activity of Preservative Solutions. The total phenolic contents of RPPE were 4534.78 mg of GAE/100 g of RPPE, and the betanin presented 55.85 mg/100 g. The DPPH radical scavenging was 18.14%, 24.19%, 31.81%, and 38.54% for *T*0, *T*1, *T*2, and *T*3 solutions, respectively. These results demonstrated that the higher RPPE addition showed a higher antioxidant activity in the coating solutions. This behavior was also observed where the samples containing with higher RPPE addition presented higher values of antioxidant activity. The ABTS radical scavenging for edible coatings solutions with 1%, 2%, and 3% RPPE was 0.19, 0.32, and 0.39 mM Trolox equivalent, respectively, and the CK and *T*0 had no antioxidant activity. This was similar to the result of DPPH radical scavenging in pomegranate peel extract- (PPE-) incorporated zein film [27]. The DPPH radical scavenging was about 40% for film-25 mg PPE. RPPE may be a good substitute for synthetic antioxidants, and the results also demonstrated that the RPPE presents antioxidant activity when added to the edible coating solutions.

3.2. pH and Electrical Conductivity Analysis. The changes in pH of crayfish are shown in Figure 2(a). The initial pH value

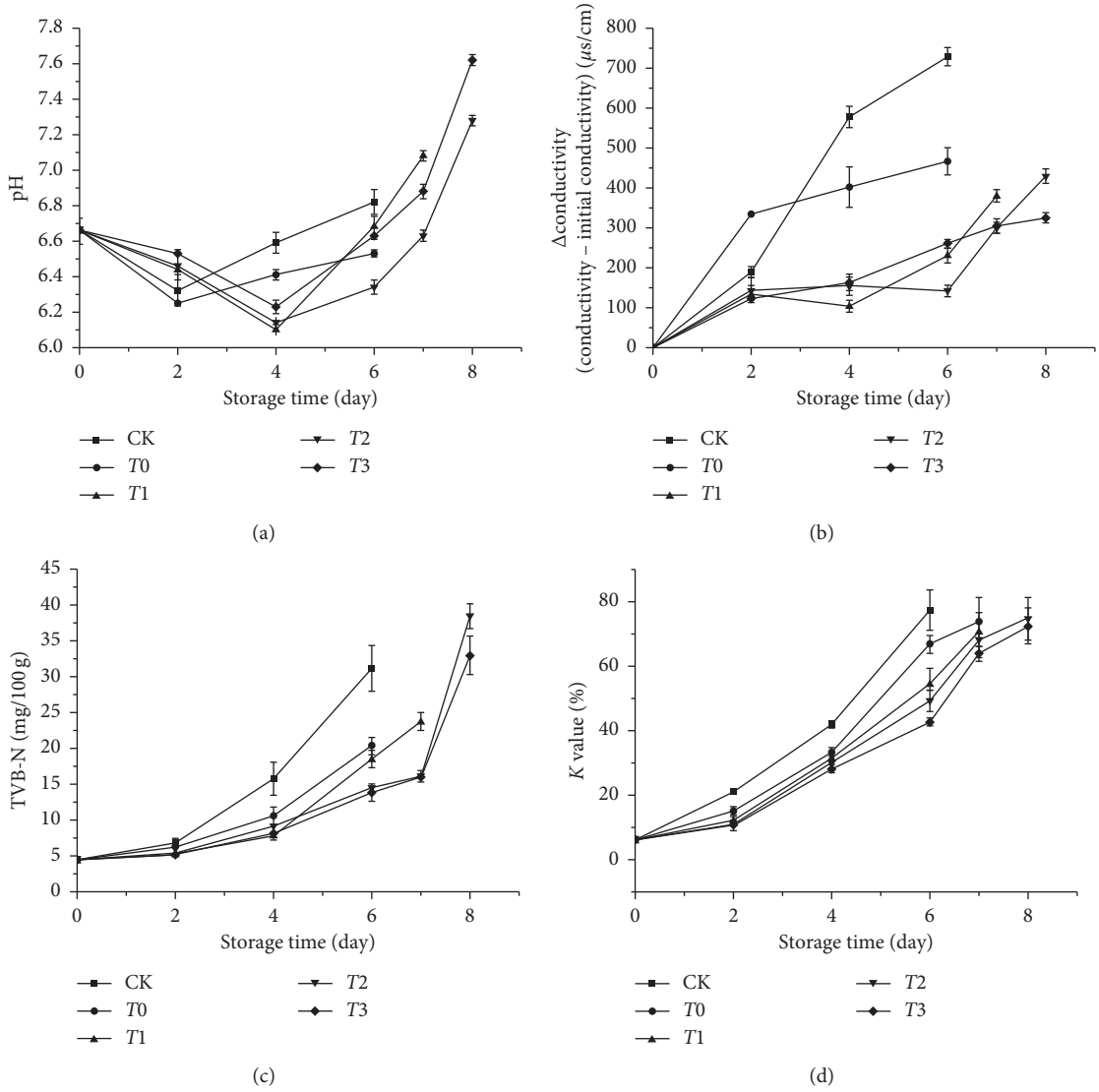

Figure 2: Change in pH values, electrical conductivity, TVB-N, and K value of crayfish during storage at 4°C.

was 6.65, and it is similar to that of white shrimp [28]. The pH of CK and $T0$ samples significantly decreased ($p < 0.05$) at first and then increased from day 2 to the end. However, the pH of $T1$, $T2$, and $T3$ samples significantly decreased ($p < 0.05$) from day 0 to day 4 and then tended to increase. The decrease in pH may due to the lactic acid produced by the glycolysis of glycogen [29]. During refrigerated storage, the volatile compounds such as trimethylamine, dimethylamine, and ammonia produced by proteolysis led to the increase of pH [30]. This result was consistent with the result of Wang et al. using chitosan-carvacrol coating on the quality of Pacific white shrimp during iced storage [31]. Electrical conductivity is an index of the concentration of electrolytes in the muscle tissue, and it can be used to characterize the texture of sample tissue [32]. The electrical conductivity value of all samples increased significantly ($p < 0.05$), while the CK and $T0$ samples showed higher values during storage (Figure 2(b)). The RPPE could slow the electrical conductivity increase, which may be due to ionic substances produced by bacteria and decomposed muscle tissues [33].

3.3. TVB-N Analysis. TVB-N value could assess the quality of freshwater products during storage, and its increase is closely associated with the degradation of protein or non-protein nitrogenous compounds by the activities of spoilage bacteria and endogenous enzymes [34]. The TVB-N value of deshelled crayfish at day 0 was 4.58 mg/100 g, and it continually increased in all the samples during storage (Figure 2(c)). The CK showed significantly higher values than $T1$, $T2$, and $T3$ ($p < 0.05$). Generally, 20 mg/100 g is the rejection limit for TVB-N values in freshwater products [35], and the TVB-N value in CK and $T0$ reached to an unaccepted level (31.13 mg/100 g and 20.32 mg/100 g, respectively) at day 6. Samples with bioactive edible coating containing RPPE had lower TVB-N values compared with CK and $T0$. $T1$ reached the unaccepted level at day 7, and $T2$

Table 1: Changes of transverse relaxation time and water distribution of crayfish during storage.

Storage time (day)	T_{21}	T_{22}	T_{23}	pT_{21}	pT_{22}	pT_{23}
0d						
	0.75 ± 0.05^{abc}	65.79 ± 2.63^{a}	464.16 ± 19.28^{a}	1.14 ± 0.01^{ab}	97.58 ± 0.04^{a}	1.28 ± 0.01^{ab}
2d						
CK	1.32 ± 0.04^{de}	65.79 ± 2.63^{a}	533.67 ± 37.36^{b}	1.05 ± 0.01^{bc}	96.38 ± 0.09^{b}	2.57 ± 0.07^{c}
*T*0	1.32 ± 0.05^{de}	75.65 ± 6.05^{b}	705.48 ± 28.22^{c}	1.24 ± 0.04^{ad}	97.04 ± 0.03^{c}	1.72 ± 0.07^{de}
*T*1	1.34 ± 0.43^{de}	75.65 ± 2.27^{b}	533.67 ± 48.03^{b}	0.99 ± 0.08^{c}	97.39 ± 0.02^{d}	1.62 ± 0.09^{e}
*T*2	1.14 ± 0.49^{ef}	65.79 ± 1.97^{a}	464.16 ± 4.52^{a}	1.30 ± 0.01^{de}	97.25 ± 0.04^{e}	1.45 ± 0.09^{f}
*T*3	0.76 ± 0.02^{abc}	75.65 ± 1.51^{b}	738.20 ± 21.45^{c}	1.41 ± 0.09^{f}	97.24 ± 0.04^{e}	1.35 ± 0.04^{a}
4d						
CK	1.52 ± 0.14^{dg}	57.22 ± 3.87^{c}	403.70 ± 32.30^{ae}	2.43 ± 0.09^{g}	95.04 ± 0.08^{f}	2.53 ± 0.05^{c}
*T*0	1.52 ± 0.09^{dg}	65.79 ± 3.95^{a}	533.67 ± 48.03^{b}	1.85 ± 0.04^{h}	96.25 ± 0.03^{g}	1.90 ± 0.05^{g}
*T*1	1.04 ± 0.08^{aef}	57.22 ± 0.51^{c}	464.16 ± 13.92^{a}	2.33 ± 0.08^{i}	96.16 ± 0.06^{g}	1.51 ± 0.04^{f}
*T*2	1.14 ± 0.25^{ef}	65.79 ± 3.29^{a}	464.16 ± 4.55^{a}	1.24 ± 0.10^{ad}	97.53 ± 0.09^{a}	1.23 ± 0.07^{b}
*T*3	0.72 ± 0.07^{abc}	57.22 ± 2.86^{c}	351.12 ± 24.58^{e}	1.38 ± 0.07^{ef}	97.49 ± 0.03^{a}	1.13 ± 0.08^{h}
6d						
CK	0.43 ± 0.01^{c}	49.77 ± 0.98^{d}	403.70 ± 16.15^{ae}	2.07 ± 0.03^{j}	94.57 ± 0.03^{h}	3.37 ± 0.04^{i}
*T*0	1.34 ± 0.27^{de}	75.65 ± 7.52^{b}	613.59 ± 36.82^{d}	1.86 ± 0.05^{h}	95.62 ± 0.04^{i}	2.51 ± 0.02^{c}
*T*1	0.87 ± 0.02^{abf}	57.22 ± 1.72^{c}	533.67 ± 36.70^{b}	2.08 ± 0.07^{j}	95.59 ± 0.03^{i}	2.32 ± 0.04^{j}
*T*2	1.75 ± 0.12^{gh}	57.22 ± 2.56^{c}	464.16 ± 26.33^{a}	1.33 ± 0.08^{def}	96.94 ± 0.08^{j}	1.73 ± 0.09^{d}
*T*3	0.66 ± 0.01^{bc}	65.79 ± 3.95^{a}	613.59 ± 30.68^{d}	1.43 ± 0.03^{fk}	95.81 ± 0.02^{k}	0.76 ± 0.08^{k}
7d						
*T*1	1.15 ± 0.05^{ef}	43.29 ± 0.87^{e}	403.70 ± 7.55^{ae}	2.47 ± 0.05^{g}	94.79 ± 0.06^{l}	2.69 ± 0.01^{l}
*T*2	2.01 ± 0.16^{h}	75.65 ± 3.02^{b}	613.59 ± 49.08^{d}	1.63 ± 0.05^{l}	96.17 ± 0.02^{g}	2.19 ± 0.02^{m}
*T*3	1.75 ± 0.13^{gh}	65.79 ± 5.52^{a}	464.16 ± 9.28^{a}	1.52 ± 0.08^{k}	96.53 ± 0.05^{m}	2.00 ± 0.06^{n}
8d						
*T*2	1.52 ± 0.14^{dg}	65.79 ± 1.97^{a}	464.16 ± 3.26^{a}	1.92 ± 0.04^{h}	96.04 ± 0.06^{n}	2.05 ± 0.05^{n}
*T*3	0.66 ± 0.07^{bc}	57.22 ± 0.36^{c}	403.07 ± 18.97^{ae}	1.08 ± 0.03^{bc}	91.27 ± 0.09^{e}	1.64 ± 0.05^{de}

Means in the same column with different letters are significantly different ($p < 0.05$).

and *T*3 reached the unaccepted level at day 8. The RPPE could delay the increase of TVB-N effectively, leading to a longer shelf life of deshelled crayfish. This is in agreement with the research reported by Morsy using pomegranate peel to improve the quality attributes of meatballs [36].

3.4. K Value Analysis. *K* value is an effective and reliable index for freshness evaluation of freshwater products [11]. The initial *K* value in samples was 6.13% (Figure 2(d)), and a gradual increase in *K* value was observed with storage time, which suggested that fish gelatin edible coating containing RPPE could keep the freshness in crayfish muscle during storage. The *K* value of all samples increased significantly ($p < 0.05$), while the CK showed higher values during storage. The *K* value in CK, *T*0, *T*1, *T*2, and *T*3 exceeded 70% (considered to be unacceptable [37]) after 6, 7, and 8 days of storage, respectively. This result was similar to the shelf life extension of crucian carp using natural preservatives during chilled storage [38].

3.5. LF-NMR. NMR transverse relaxation T_2 indicates three different types of water, which are as follows: the bound water entrapped within tertiary and quaternary protein structures, immobile water within the myofibril, and free water in the extramyofibrillar space, corresponding to T_{21} (0.01 to 10 s), T_{22}, (10 to 100 ms), and T_{23} (100 to 1000 ms), respectively [24]. Furthermore, the integral area of different transversal relaxation times in the percentage of the total integral area could reflect the content of different forms of water [39]. In the research, T_{21} changed slightly for all the samples; however, T_{22} decreased and T_{23} fluctuated without regular trends during storage. This result indicated that the changes of free water were more obvious than those of bound and immobile water in deshelled crayfish samples with the storage time. pT_{21}, pT_{22}, and pT_{23} corresponded to the areas of relaxation times T_{21}, T_{22}, and T_{23} (Table 1). Obviously, pT_{21} and pT_{23} increased observably; however, pT_{22} diminished progressively during storage, and pT_{22} took the largest proportion of three types of water. No significant differences ($p > 0.05$) was detected among the immobilized water in *T*3 compared with other samples, probably due to that more RPPE addition could retard the immobilized water within the myofibril to free water and keep excellent quality of crayfish muscle.

3.6. FAA Analysis. FAAs are responsible for the formation of flavor and can be the precursor of aromatic compounds. The increase of FAA content is due to protein and peptide decomposition induced by proteolytic enzymes, while its decrease is due to the reaction of these amino acids with other compounds [40]. The major FAAs in deshelled crayfish were Arg, Thr, Ala, and Gly, which accounted for 76.08–87.92% of total FAAs (Table 2). As a flavor-stale amino acid, His of CK

Table 2: FAA contents of crayfish sample during storage at 4°C.

FAA (mg/100 g)	0d	4d				8d			
	0d	CK	*T*0	*T*1	*T*2	*T*3	*T*0	*T*1	*T*2	*T*3
Asp	0.23	0.74	1.12	1.35	0.59	1.10	2.13	1.28	1.97	1.55
Thr	148.62	83.68	104.36	74.56	59.79	83.13	103.88	79.88	101.68	123.19
Ser	50.23	—	—	—	7.87	4.35	10.26	—	—	15.24
Glu	9.66	17.02	15.07	18.58	8.98	12.50	23.12	79.40	21.25	17.61
Gly	54.98	34.37	58.25	24.50	19.62	54.15	31.49	54.80	27.62	38.87
Ala	127.00	74.76	118.67	79.78	72.55	87.03	96.12	125.67	93.26	86.41
Val	18.70	17.27	18.21	16.06	10.02	16.01	24.53	14.50	21.72	20.60
Met	16.54	12.15	11.58	12.38	7.29	7.83	14.12	15.06	11.73	11.52
Ile	9.80	6.18	6.97	6.48	5.36	7.41	10.65	6.22	9.76	10.39
Leu	17.80	12.22	13.12	11.56	9.27	12.97	18.82	11.31	18.45	18.95
Tyr	4.97	5.90	5.58	4.89	4.46	4.34	7.75	7.34	6.75	5.65
Phe	5.53	6.21	5.70	6.66	4.44	4.54	11.18	6.28	9.85	6.46
Lys	29.95	7.95	20.17	10.97	19.33	14.04	17.54	32.11	16.27	39.64
His	23.43	35.05	30.02	33.49	20.99	25.98	42.70	33.25	36.10	31.78
Arg	616.35	449.14	497.42	501.77	449.01	440.67	530.66	429.67	472.56	584.79
Total	1133.78	762.64	906.24	803.03	699.56	776.05	944.98	896.77	848.97	1012.65

—, not detected.

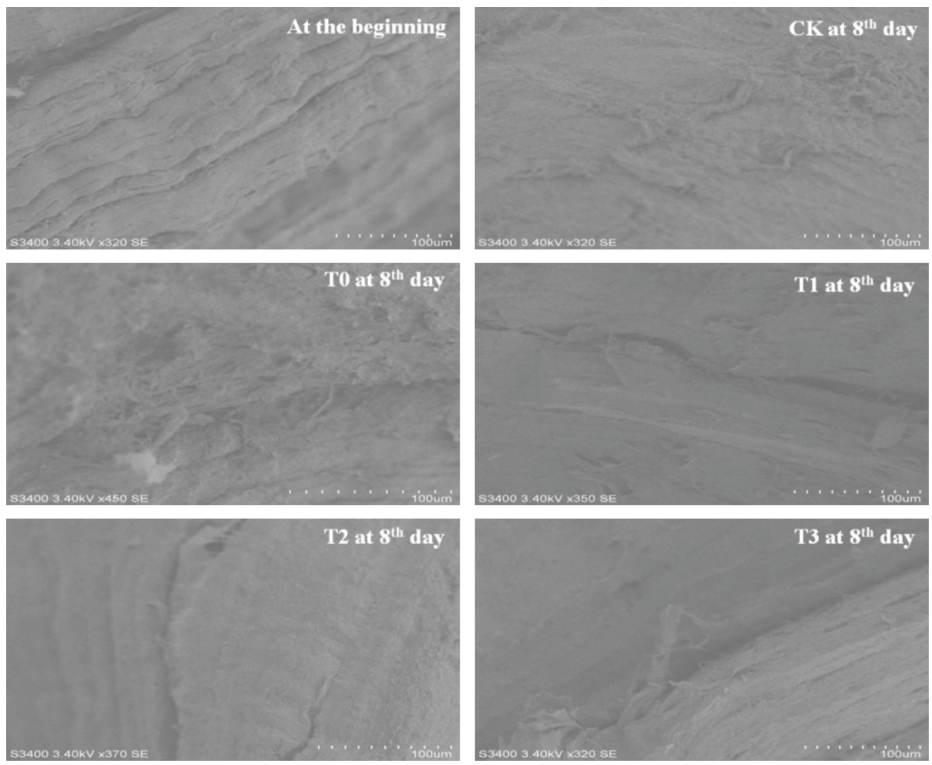

Figure 3: SEM images of crayfish under different treatments during storage. (a) At the beginning. (b) CK at 8th day. (c) *T*0 at 8th day. (d) *T*1 at 8th day. (e) *T*2 at 8th day. (f) *T*3 at 8th day.

increased from the initial value of 23.43 mg/100 g to 30.02 mg/100 g at day 4, while the content of *T*0, *T*1, *T*2, and *T*3 were 42.70, 33.25, 36.10, and 31.78 mg/100 g at day 8, respectively. His was basically caused by the oxidation process from trimethylamine oxide based on the growth of the spoilage organism and was consistent with results of the TVB-N value. Arg, Thr, Met, Ile, and Lys showed upwards trends at the early storage and afterwards gradually decreased; however, Asp, Glu, Tyr, and His showed upwards. Ala and Gly progressively decreased during storage, which was owing to the positive enhancing effects of desired tastes and characterized by sweetness [41, 42]. The decrease of special flavor-enhancing amino acids and accumulation of flavor-detracting amino acids could lead to the flavor deterioration, and the coating with RPPE could effectively slow down the process and maintain the quality of deshelled crayfish.

3.7. Microstructure of Crayfish Muscle. Representative SEM microstructures of crayfish muscle subjected to the RPPE treatments were compared with fresh crayfish muscle in

Figure 3. We observed significant differences between the fresh crayfish muscle and those treated with RPPE both in fibers, bundles, and intramuscular connective tissues. At day 0, fresh crayfish had a complete and smooth muscle structure and a compact muscle fiber arrangement (Figure 3). Some small spaces appeared between the muscle bundles in the fresh sample, all of which indicated a well-organized structure. With the prolongation of storage time, the muscle fiber tissues in the treated groups had different degrees of deterioration. At day 8, the muscle structure of the CK and *T*0 samples were most degraded and the surface texture was loose and fuzzy. Although degradation was also observed in the *T*1 and *T*2 samples, the fibers, bundles, and structures were still regular in appearance. The muscle fiber of *T*3 was more regular, and the muscle fiber was not significantly broken. The connective tissues also adhered to each other tightly, which were very similar to those of the fresh sample. Therefore, RPPE delayed the degradation of crayfish muscle.

4. Conclusion

RPPE exhibited a high amount of total phenolic and demonstrated effective antioxidant properties. Gelatin coating with RPPE and *ε*-PL delayed deshelled crayfish deterioration in quality parameters, such as TVB-N, *K* value, FAAs, and water migration and could extend deshelled crayfish shelf life by 2 days. Combined with the effect of the color of the preservation solution on the samples, the coating combined with 2.0% RPPE was preferred.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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