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Components and nutritional quality of shrimp processing by-products

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Abstract

The components and nutritional quality of processing by-products (heads, shells and tails) of Northern pink shrimp (NPS, *Pandalus borealis*) and spotted shrimp (SS, *Trachypena curvirostris*) caught near Tongyeong, Korea, were investigated. Crude protein contents were in the range of 9.3–11.6% and total fat content was approximately 0.7%. Volatile basic nitrogen (VBN) values of the processing by products were lower than those of the edible parts. The number of viable cells (CFU/g) was $1.2–2.8\times10^4$, which is acceptable for seafood processing, and heavy metals (Hg, Pb and Cd) were present in trace amounts. Aspartic acid, glutamic acid, phenylalanine, lysine and arginine were the predominant amino acids in the protein fraction. The calcium content (3000 mg/100 g) was higher than those of phosphorus (400 mg/100 g), sodium (270 mg/100 g) and magnesium (100 mg/100 g) while manganese and iron were present in trace amounts. There was no significant difference in the non-protein nitrogen contents between the edible parts and the processing by-products of shrimp. The total content of free amino acids of the processing by-products (2000 mg/100 g) was 15% higher than that of the edible parts (1700 mg/100 g). Major free amino acids were taurine, threonine, leucine, tryrosine and phenylalanine.

Keywords: Shrimp processing by-product; Nutritional quality

1. Introduction

Shrimp is rich in protein, calcium, vitamins and various extractable compounds and has been used as one of the most popular and important raw materials for many Korean dishes, especially in the production of salt-fermented shrimp (Jeot-gal; Han, 1997). Generally, the head, shell and tail portions of shrimp are removed during processing and these account for approximately 50% of the catch. Recently, with the rapid growth of the fast food industry, consumption of shrimp has increased. Increasing production of inedible parts of shrimp, such as heads, shells and tails, is causing environmental problems as a result of uncontrolled dumping. Thus, attention must be paid to greater utilisation of shrimp processing by-products in order to address such concerns. Studies on shrimp have included those on the physicochemical properties of salt-fermented shrimp (Mok & Song, 2000; Mok et al., 2000), shrimp freshness during cold storage (Jeong, Jo, Lim, & Kang, 1991; Lee & Um, 1995), flavour components (Lee, Ahn, Oh, & Lee, 1986), characteristics of shrimp by-product and proteases (Doke & Ninjoor, 1987; Shahidi & Synowiecki, 1991), and natural antioxidant extraction from shrimp (Pasqual & Babbitt, 1991). Efforts have also been underway to utilize shrimp shell by-products for the extraction of carotenoprotein (Camo-Lopez, Simpson, & Haard, 1987; Simpson & Haard, 1985), chitin (Johnson, 1987; Shahidi, Arachchi, & Jeon, 1999), chitosan (Benjakul & Sophanodora, 1993; Chung, Kim, Hur, & No, 1996; Simpson & Haard, 1985) and their application in food processing (Jeon, Shahidi, & Kim, 2000; Shahidi, Arachchi, & Jeon, 1999). However, there are few studies on the utilization of shrimp by-products, including heads, shells and tails. The objective of this study was to investigate the components and nutritional

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quality of shrimp processing by-products in order to explore possibilities for their utilization.

2. Materials and methods

2.1. Sample

Northern pink shrimp (NPS, *Pandalus borealis*) and spotted shrimp (SS, *Trachypena curvirostris*) were used as raw materials; samples were stored at −70 °C until used. Whole shrimps, caught near Tongyoung, Korea, were purchased from a commercial fish market. Inedible parts (processing by-products; heads, shells and tails) were separated from the whole body, frozen, pulverized and stored at −70 °C until used.

2.2. Proximate composition, pH, salinity and volatile basic nitrogen (VBN)

According to the AOAC (1990) methods, moisture was quantified by oven-drying at 105 °C, total fat by Soxhlet extraction, crude protein by Kjeldahl procedure, and crude ash by incineration in a muffle furnace at 550 °C. The carbohydrate content was calculated by weight difference. Samples for pH and salinity measurements were prepared by adding 5 g of each sample to 10 volumes of deionized water, and then homogenized. Salinity was determined by a salt meter (Istek model 460CP, Seoul, Korea) and pH was measured using a pH meter (Metrohm model 744, Switzerland). The concentration of VBN was determined by the method of Conway (1950).

2.3. Total viable cells

The total viable cells were determined by the standard plate count method (Richardson, 1985). One half gram of the sample was ground, homogenized and diluted 10-fold each time. Each dilution was used to spread on agar plates, and the number of colonies formed was counted after 48 h of culture.

2.4. Lipid extraction and fatty acid compositions

Total lipid (TL) was extracted according to the method of Bligh and Dyer (1959).

Fatty acid composition was determined, following transmethylation (AOCS, 1990), by gas chromatography (Shimadzu GC 14A, Shimadzu Seisakusho, Co. Ltd., Kyoto, Japan) using an Omegawax 320 fused silica capillary column (30 m×0.320 mm, ID., Supelco Park, Bellefonte, PA). Fatty acids were identified by comparison of their retention times with those of authentic standards (Sigma Chemical Co., St Louis, MO) and their contents calculated on a weight percentage basis.

2.5. Total and free amino acid compositions

Total amino acid composition was determined using an amino acid analyzer (Biochrom 20, Pharmacia Biotech, Sweden). Samples were hydrolyzed in 6 M HCl in evacuated sealed tubes at 110 °C for 24 h. For determination of sulphur-containing amino acids, samples were added to dimethyl sulfoxide (DMSO) in order to obtain a final concentration of 0.2 M and then hydrolyzed in 6 M HCl (Spencer & Wold, 1969). Free amino acids were extracted in 80% ethanol and deproteinized with 5-sulfosalicylic acid. The free amino acid profiles of the samples were determined, as before. Extractive nitrogen(Ex-N) was determined using the Kjeldahl method (AOAC, 1990)

2.6. Minerals and phosphorus determination

Minerals and phosphorus were determined by the wet ashing method of Tsutagawa, Hosogai, and Kawai (1994) using nitric acid. The samples, after ashing, were analyzed using an inductively coupled plasma spectrophotometer (ICP, Atomscan 25, Thermo Electron Co., Waltham, MA).

2.7. ATP and its related compounds

The ATP and its related compounds were determined by an HPLC (LC-10AT vp, Shimadzu, Kyoto, Japan) procedure at a flow rate of 1 ml/min according to the method of Ryder (1985). The samples were extracted with 10% cold perchloric acid, adjusted to neutral pH (6.8–7.2) with a 2 M potassium hydroxide solution, and then injected to a μ-Bondapak C_{18} column (ID 3.9×300 mm, particle size 10 μm, Waters, Ireland) equilibrated with 50 mM potassium phosphate buffer, pH 6.4. Elution profile was monitored with an UV detector (SPD-10AV vp, Shimadzu, Kyoto, Japan) at 254 nm.

Trimethylamine oxide (TMAO) and trimethylamine(TMA) were determined according to the method of Hashimoto and Okaichi (1957) and total creatinine was measured by the colorimetric procedure described by Chase, Grady, and Stanley (1961).

3. Results and discussion

3.1. Yield of shrimp processing by-products

The yield of muscle and processing by-products of Northern pink shrimp (NPS, *P. Borealis*) and spotted shrimp (SS, *T. Curvirostris*) are shown in Table 1. Muscle contents were 48.1% (w/w) in NPS and 48.3% in SS, almost half of the weights of whole shrimps. Heads were 38.9 and 37.9% in NPS and SS, respectively. Shells contributed 10.7% of NPS and 11.5% of

Table 1
Size and yields of shrimp processing by-products

Components	Northern pink shrimp (NPS)	Spotted shrimp (SS)
Body length (cm)	10.5–12.0(11.2±0.5)[a]	8.5–9.5(9.0±0.3)
Weight (g)		
Muscle	5.4–6.9(6.3±0.5)	3.7–4.9(4.2±0.5)
Head	4.5–5.7(5.1±0.5)	1.8–4.4(3.3±0.7)
Shell	1.2–1.5(1.4±0.1)	0.4–2.4(1.0±0.6)
Tail	0.1–0.4(0.3±0.1)	0.1–0.3(0.2±0.1)
Total	11.8–14.2(13.1±1.0)	6.4–10.7(8.7±1.4)
Yields (%)		
Muscle	48.1	48.3
Head	38.9	37.9
Shell	10.7	11.5
Tail	2.3	2.3
Total	100.0	100.0

[a] Values in the parentheses are means of ten determinations± standard deviation.

SS, while the tails were 2.4% of NPS and 2.3% of SS. Processing by-products contributed approximately 52% to the total weight of shrimp processed. Thus, it is very important, economically and industrially, that these processing by-products be used.

3.2. Proximate composition, pH and salinity

Proximate composition, pH and salinity of muscle and by-products of NPS and SS are shown in Table 2. Moisture in muscle was higher than that in the by-products. The crude protein contents of muscle were 13.4% in NPS and 14.9% in its by-products; the latter might include a contribution from chitin. Meanwhile, the total lipid contents of the by-products were 0.6% (NPS) and 0.7% (SS) which are higher than those of the muscle (0.4% of NPS and 0.3% of SS). The by-products had a higher crude ash content (8.2% in NPS and 7.0% in SS) when compared with that of the muscle. Thus, there was only a slight difference between proximate compositions of the two species.

Table 2
Proximate composition, pH and salinity of muscle and processing by-products of northern pink shrimp (NPS) and spotted shrimp (SS)[a]

Components	NPS		SS	
	Muscle	By-products	Muscle	By-products
Moisture	84.4±0.0	79.1±0.8	83.1±0.1	78.5±0.0
Crude protein	13.4±0.3	9.3±0.3	14.9±0.5	11.6±0.2
Total lipid	0.4±0.0	0.6±0.1	0.3±0.1	0.7±0.2
Crude ash	1.6±0.1	8.2±0.1	1.5±0.1	7.0±0.2
pH	8.05±0.13	8.98±0.04	7.76±0.04	8.94±0.01
Salinity	0.89±0.02	0.80±0.02	0.86±0.00	0.68±0.05

[a] Values are means of triplicate determinations±standard deviation

The pH of the by-products of NPS and SS were 8.98 and 8.94, respectively. The salinities of muscle and by-products were less than 1%. Based on their proximate compositions, shrimp processing by-products may serve as a good source of minerals and protein, among others, for a variety of applications.

3.3. Volatile basic nitrogen, viable cells and heavy metal content

Volatile basic nitrogen (VBN), viable cells and heavy metal contents of shrimp processing by-products are shown in Table 3. Volatile basic nitrogen contents of the by-products were 9.8 mg/100 g in NPS and 5.6 mg/100 g in SS while those of the muscle were 12.6 mg/100 g in NPS and 11.9 mg/100 g in SS. The amounts of VBN were less than 20 mg/100 g, which are thought to be the acceptable limit for marine products (Park, Kim, Kim, & Park, 1996), and were also lower than 13.0 mg/100 g where a decrease in freshness is acknowledged during low temperature storage (Lee & Um, 1995). VBN of by-products was 77.7% in NPS and 47.1% in SS in comparison with those of the muscle. Therefore, shrimp processing by-products are considered to be acceptable materials in terms of their freshness status.

Viable cells in the by-products were 2.8×10^4 CFU/g in NPS and 1.2×10^4 CFU/g in SS while they were present at 3.1×10^4 CFU/g in both NPS and SS muscles. These values are less than 1×10^5 CFU/g which is considered as the upper limit and, thus shrimp by-products may be considered acceptable for use as food materials (Park, Kim, Park, & Kim, 1995).

The reason why shrimp by-products have less VBN and live bacteria than muscle might be due to the fact that by-products were washed with water or a sodium erythorbate solution, the latter being used to prevent darkening of the products and hence removing some of their microorganisms.

Table 3
Volatile basic nitrogen (VBN) content, viable cell counts and heavy metal contents of muscle and processing by-products of northern pink shrimp (NPS) and spotted shrimp (SS)

Components	NPS		SS	
	Muscle	By-products	Muscle	By-products
VBN (mg/100 g)[a]	12.6±0.0	9.8±0.0	11.9±1.0	5.6±0.0
Viable cells (CFU/g)	3.1×10^4	2.8×10^4	3.1×10^4	1.2×10^4
Heavy metals (ppm)[a]				
Mercury	Trace	Trace	Trace	Trace
Copper	2.5±0.0	7.4±0.1	1.9±0.1	6.8±0.1
Zinc	10.2±0.0	13.9±0.1	10.0±0.1	13.8±0.2
Lead	Trace	0.3±0.1	Trace	Trace
Cadmium	Trace	0.3±0.0	Trace	Trace

[a] Values are means of triplicate determinations±standard deviation.

Mercury was present only in trace amounts in both muscle and by-products. Copper was present in the muscle at 2.5 ppm in NPS and 1.8 ppm in SS while it was found at 7.4 ppm in by-product of NPS and 6.8 ppm in SS. Zinc was present at 10 ppm in the both the muscle and the by-products. Stanley and Wilt (1971) reported the heavy metal safety values: 1.5–3.5 ppm for cadmium, 42–173 ppm for copper, 2.0 ppm for lead, 1000–2000 ppm for zinc and 0.2 ppm for mercury. The levels of heavy metals in by-products of NPS and SS were below these safety limits; therefore shrimp processing by-products may be considered as safe from the standpoint of their heavy metal contents.

3.4. Fatty acid compositions

Fatty acid compositions of muscle and by-products of NPS and SS are shown in Table 4. The contents of polyenes in the muscle of NPS and SS were 50 and 51.4%, respectively, which are somewhat higher than those in the by-products (NPS, 43.9%; SS, 48.3%). There was no significant difference in the content of saturated fatty acids between muscle (NPS, 25.4%; SS, 26.2%) and by-products (NPS, 25.9%; SS, 26.1%). Monoenes in by-products were present at 24.2% (NPS) and 25.0% (SS) while those in the muscle were 24.2% (NPS) and 22.1% (SS). There was no difference between species of shrimp, but monoene content of NPS was higher than that of SS by 2–4%. Major fatty acids of muscle and by-products were 16:0 (13.1–16.3%), 18:1n-9 (6.3–10.2%), 20:5n-3 (8.9–13.2%) and 22:6n-3(10.7–14.5%). Thus, shrimp products and by-products contained high amounts of n-3 long chain polyunsaturated fatty acids, such as eicopentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) and hence may contribute to the prevention of diseases related to geriatric and cardiovascular disorders and certain forms of cancer, among others (Yazawa & Kageyama, 1991). However, the crude lipid content in shrimp processing by-products is too low to serve as a source of these important fatty acids. When these materials were used as a protein source, lipid oxidation did not affect the quality of either the muscle or the by-products.

3.5. Total amino acid composition

Total amino acid composition of NPS and SS is shown in Table 5. Total amino acid content of by-products of SS was 10,297 mg/100 g, 71.1% of that of muscle (14,479 mg/100 g) while the total amino acids of NPS by-products was 8134 mg/100 g, 64.6% of that of muscle (12,588 mg/100 g). By-products of SS showed a higher content of amino acids than NPS, so SS by-products would serve as a better protein source. Major amino acids in the by-products of NPS and SS were phenylalanine and glutamic acid which constituted approximately 31% of the total amino acids. Shrimp processing by-products had a high content of lysine (NPS, 1143 mg/100 g; SS, 1300 mg/100 g); hence they may serve as a good complement in the diet of Koreans and Asians whose food is mainly grain-based (Kim, 2000) and low in lysine.

3.6. Mineral and phosphorus contents

Mineral contents of NPS and SS are shown in Table 6. As expected, calcium (NPS, 3371 mg/100 g; SS, 3040

Table 4
Fatty acid compositions of total lipids in shrimp muscle and processing by-products (wt.%)

Fatty acids	Northern pink shrimp		Spotted shrimp	
	Muscle	By-products	Muscle	By-products
12:0	0.1	0.1	0.1	0.1
14:0	1.1	2.0	1.8	2.1
15:0iso	0.4	0.8	0.2	0.4
15:0	1.3	1.5	2.0	2.2
16:0iso	0.5	0.7	0.9	0.6
16:0	16.3	14.8	14.4	13.1
17:0	0.7	0.2	0.4	0.3
18:0	5.0	5.8	6.4	7.3
20:0	0.4	0.6	0.3	0.6
Saturates	**25.4**	**25.9**	**26.2**	**26.1**
16:1n-7	5.0	6.1	5.5	6.7
16:1n-5	1.3	1.8	1.5	1.4
18:1n-9	10.2	9.3	8.0	6.3
18:1n-7	3.9	5.5	4.3	5.1
18:1n-5	0.5	0.6	0.3	0.3
20:1n-9	1.2	3.1	0.7	2.1
20:1n-7	0.9	1.3	0.8	1.3
2:1n-11	0.8	0.8	0.4	0.6
22:1n-9	0.3	0.9	0.3	0.8
22:1n-7	0.1	0.2	0.3	0.4
Monoenes	**24.2**	**29.6**	**22.1**	**25.0**
16:2n-9	0.9	1.5	1.1	1.2
16:2n-4	1.8	1.8	2.7	2.6
16:3n-4	1.2	1.1	2.0	3.2
16:4n-3	1.0	1.1	0.9	0.7
16:4n-1	0.4	0.5	0.9	0.5
18:2n-6	1.4	1.4	0.9	0.7
18:2n-4	0.7	0.4	0.4	0.5
18:3n-4	0.4	0.3	0.3	0.4
18:3n-3	0.8	0.6	0.3	1.0
18:4n-3	0.2	0.3	0.1	0.3
20:2n-9	1.3	2.9	0.7	2.4
20:2n-6	1.2	1.7	0.8	1.1
20:3n-6	0.8	0.5	0.3	0.5
20:4n-6	6.7	5.5	8.2	6.7
20:4n-3	0.4	0.4	0.2	0.3
20:5n-3	11.6	8.9	13.2	10.7
21:5n-3	0.6	0.4	0.4	0.4
22:4n-6	1.1	1.3	0.9	1.5
22:5n-6	1.0	0.8	0.9	0.9
22:5n-3	2.0	1.8	2.0	1.8
22:6n-3	14.5	10.7	14.2	10.9
Polyenes	**50.0**	**43.9**	**51.4**	**48.3**

mg/100 g) was present in higher amounts in the by-products. Phophorus and magnesium in by-products were much higher than those in the muscle. Contents of iron and manganese were comparatively low when considering other minerals. Even though by-products might be considered as a good source of calcium, their ratio of calcium to phosphorus was about 7:1 which is not adequate for use by humans (Tsutagawa, Hosogai, & Kawai, 1994). The calcium contents in shrimp by-products were less than those of fish bone (Kim, Choi, & Kim, 1998).

Table 5
Total amino acid contents of shrimp muscle and processing by-products (mg/100 g)[a]

Amino acid	Northern pink shrimp		Spotted shrimp	
	Muscle	By-products	Muscle	By-products
Aspartic acid	1180(9.5)	664(8.2)	1281(8.8)	882(8.6)
Threonine	539(4.3)	325(4.0)	664(4.6)	488(4.7)
Serine	540(4.3)	336(4.1)	597(4.1)	462(4.5)
Glutamic acid	1778(14.2)	920(11.3)	2113(15.3)	1143(11.1)
Proline	297(2.4)	292(3.6)	560(3.8)	429(4.2)
Glycine	1105(8.8)	473(5.8)	1000(6.9)	608(5.9)
Alanine	736(5.9)	403(5.0)	820(5.6)	533(5.2)
Cysteine[b]	356(2.1)	277(3.4)	399(2.7)	202(2.0)
Valine	718(5.8)	463(5.7)	872(6.0)	600(5.8)
Methionine[b]	225(1.8)	125(1.5)	263(1.8)	87(0.8)
Isoleucine	523(4.2)	277(3.4)	725(5.0)	344(3.3)
Leucine	975(7.8)	458(5.6)	1092(7.5)	573(5.6)
Tyrosine	323(2.6)	205(2.5)	337(2.3)	195(1.9)
Phenylalanine	588(4.7)	1585(19.5)	705(4.8)	2059(20.0)
Histidine	343(2.7)	184(2.3)	390(2.7)	269(2.6)
Lysine	1143(9.1)	574(7.1)	1301(8.9)	723(7.0)
Arginine	1219(9.8)	574(7.1)	1360(9.3)	702(6.8)
Total	12,58(100)	8134(100)	14,479(100)	10,297(100)

Tryptophan was not determined.

[a] Values in the parentheses are the percentage of total amino acid contents.

[b] Values for cysteine and methionine are underestimated as they were not determined separately.

Table 6
Important mineral and phosphorus contents of shrimp muscle and processing by-products (mg/100 g)[a]

Mineral	Northern pink shrimp		Spotted shrimp	
	Muscle	By-products	Muscle	By-products
Calcium	96.5±0.75	3371±30.6	71.3±0.24	3040±18.9
Phosphorus	167±5.03	338±6.81	178±8.05	400±12.6
Sodium	254±3.21	282±1.97	246±2.39	267±2.48
Magnesium	50.7±0.45	141±0.99	32.3±0.26	104.05±0.30
Potassium	144±3.85	71.2±1.30	163±0.40	98.02±0.88
Manganese	0.08±0.00	0.83±0.01	0.05±0.00	0.55±0.00
Iron	2.15±0.03	7.29±0.03	1.91±0.02	5.63±0.02

[a] Values are mean values of three determinations±standard deviation.

3.7. Extractive nitrogen and free amino acid compositions

The contents of non-protein nitrogen in shrimp muscle and its processing by-products are shown in Table 7. The non-protein nitrogen content of by-products of NPS was 507 mg/100 g, accounting for 89.9% of that present in the muscle (564 mg/100 g). Non-protein nitrogen content of by-products of SS was 545 mg/100 g, which represents 94.0% of that in shrimp muscle (579 mg/100 g). These results suggest that shrimp by-products include, not only shells, which contain chitin, but also heads and tails which contain large amounts of extractive compounds. The extractive compounds may potentially serve as a good source of seasoning.

The free amino acid contents of shrimp by-products are given in Table 8. Free amino acids provide one of the main components of non-protein nitrogen compounds, which significantly influence the taste of foods. Total amount of free amino acids in by-products of SS was 2014 mg/100 g, which is higher than that in the muscle (1784 mg/100 g) by 13%, while that of NPS was 1975 mg/100 g, 18.6% higher than that of its corresponding muscle (1659 mg/100 g). Major free amino acids of NPS and SS by-products were taurine, threonine, proline, leucine, tyrosine, phenylalanine, lysine, and arginine while those of muscle were taurine, glutamine, proline, glycine, and arginine. Were shrimp by-products to be used as a source of seasoning, the spectrum and concentration of free amino acids would greatly influence their quality.

The taste threshold of free amino acids (each amino acid content/taste threshold) was calculated according to Kato, Rheu, and Nishimura (1989). The taste threshold values of by-products of NPS and SS, with reference to aspartic acid, were 15.7 and 13.3, respectively. The taste values of NPS and SS with reference to glutamic acid were 23.4 and 18.5, respectively. This latter value is much higher than those of other amino acid taste values. It is suggested that amino acids such as aspartic acid and glutamic acid, would most influence the taste. However, in muscle, glutamic acid (SS, 16.54; NPS, 17.16) and arginine (SS, 5.40; NPS, 5.16) were major amino acids and thus may contribute significantly in influencing the taste.

Table 7
Non-protein nitrogen contents of shrimp muscle and processing by-products (mg/100 g)[a]

Components	Northern pink shrimp	Spotted shrimp
By-products	507±25.3	545±24.8
Muscle	564±20.1	579±18.8

[a] Values are means of three determinations±standard deviation.

Table 8
Free amino acid contents of shrimp muscle and processing by-products (mg/100 g)[a]

Amino acids	Taste threshold (mg/dl)[b]	Northern pink shrimp		Spotted shrimp	
		Muscle	By-products	Muscle	By-products
Phosphoserine	NA	12.1	32.2	10.1	11.5
Taurine	NA	110.3	117	135	130.8
Aspartic acid	3	11.3(3.77)	47.1(15.7)	4.8(1.60)	39.9(13.3)
Threonine	260	71.7(0.28)	106(0.41)	86.9(0.33)	105(0.52)
Serine	150	67.6(0.45)	65.6(0.44)	70.2(0.47)	58.9(0.39)
Asparagine	100	77.6(0.78)	110(1.10)	93.8(0.94)	85.0(0.85)
Glutamic acid	5	85.8(17.16)	117(23.4)	82.7(16.5)	92.5(18.5)
Glutamine	NA	79.5	75.6	119	78.5
Sarcosine	NA	2.5	0.5	ND	0.7
α-Aminodipic acid	NA	1.1	1.5	ND	1.1
Proline	300	213(0.71)	87.8(0.29)	234(0.78)	109(0.36)
Glycine	130	167(1.29)	53.6(0.41)	183(1.40)	52.5(0.40)
Alanine	60	118(1.97)	68.0(1.13)	26.7(0.45)	75.8(1.26)
Citrulline	NA	69.2	49.4	41.9	35.1
Valine	140	50.9(0.36)	92.9(0.66)	68.0(0.49)	93.0(0.66)
Cysteine	NA	3.5	12.8	8.7	16.4
Methionine	30	1.6(0.05)	37.1(1.24)	2.3(0.08)	39.2(1.31)
Isoleucine	90	34.4(0.38)	80.4(0.89)	45.1(0.50)	82.8(0.92)
Leucine	190	53.9(0.28)	112(0.59)	68.9(0.36)	114.2(0.60)
Tyrosine	NA	34.7	116.6	42.9	101.1
β-Alanine	NA	4.1	3.1	2.3	4.1
Phenylalanine	90	33.0(0.37)	112(1.25)	42.9(0.48)	119(1.32)
Ornithine	NA	15.5	35.7	34.7	77.9
Lysine	50	55.7(1.11)	95.5(1.91)	64.7(1.29)	109(2.18)
Histidine	20	30.1(1.51)	64.7(3.24)	45.1(2.26)	62.0(3.10)
Anserine	NA	ND	51.3	ND	71.0
Carnosine	NA	ND	25.7	ND	35.5
Arginine	50	258(5.16)	204(4.09)	270(5.40)	214(4.27)
Total		1659	1974.8	1784	2014

[a] Numbers in parentheses represent taste value of free amino acid contents divided by taste threshold; NA, not available; ND, not detected.
[b] Data from Kato et al. (1989).

3.8. ATP-related compounds, trimethylamine(oxide) and total creatinine content

The contents of ATP-related compounds, trimethylamine(oxide) and total creatinine in shrimp by-products are shown in Table 9. The total amount of ATP-related compounds of SS by-products was 328 mg/100 g, approximately 63% of that of the muscle (519 mg/100 g). For by-products of NPS, the corresponding value was 338 mg/100 g which is 61% of that of the muscle (552 mg/100 g). IMP (inosine monophosphate) content of NPS muscle was 290 mg/100 g and that of SS was 367 mg/100 g, but those of the by-products were 56.5 mg/100 g and 83.7 mg/100 g, respectively. In addition, inosine(HxR) contents of by-products of NPS and SS were 258 and 213 mg/100 g, respectively. The nucleic acid related compounds of shrimp by-products consisted mainly of inosine and IMP.

The TMAO is responsible for the refreshing sweet taste of marine extractive compounds and it also regulates osmotic pressure of marine organisms. TMAO content of SS by-products was 32.9 mg/100 g, which is 19% of that of the muscle (173 mg/100 g), and that of NPS by-products was 27.4 mg/100 g accounting for only 22% of that of the muscle (123 mg/100 g). The TMAO content of SS by-products was higher than that of NPS by-products. The content of TMA, resulting from TMAO, was 1.3–2.7 mg/100 g in both the muscle and by-products.

Creatinine is widely known to be responsible for the astringent taste of marine products (Russel & Baldwin, 1975). Creatinine content of shrimp by-products (SS, 31.6 mg/100 g; NPS, 40.6 mg/100 g) was higher than that of the muscle (SS, 13.3 mg/100 g; NPS, 11.2 mg/100 g). In by-products, creatinine content of NPS was higher than that of SS. The results, thus suggest that free amino acids of shrimp by-products consist mainly of glutamic acid and aspartic acid, while ATP-related compounds present were IMP and inosine. These, together with TMAO and creatinine, may act synergistically to contribute to the desirable taste of shrimp-based products.

Table 9
Contents of ATP-related compounds, trimethylamine (oxide) and total creatinine in shrimp muscle and processing by-products (mg/100 g)[a]

Nucleotides	Northern pink shrimp		Spotted shrimp	
	Muscle	By-products	Muscle	By-products
ATP	5.95	6.8	ND	9.97
ADP	ND	ND	10.3	ND
AMP	33.1	4.15	17.8	4.60
IMP	290	56.5	367.13	83.7
Inosine	215	258.	117	213
Hypoxanthine	7.32	11.8	6.88	16.7
Total	556	338	519	328
TMAO	123±10.0	27.4±3.8	173±2.7	32.9±6.5
TMA	1.3±0.0	2.1±0.4	1.7±0.0	2.7±0.3
Total creatinine	11.2±0.0	40.6±1.9	13.3±1.8	31.6±0.6

[a] Values are means of three determination±standard deviation;

4. Conclusions

The contents of crude protein in shrimp by-products were lower than those of the corresponding muscle while the reverse was true for their contents of total lipid. Volatile basic nitrogen (VBN) values of shrimp by-products were lower (5.6–9.8 mg/100 g) than those of the edible parts (11.9–12.6 mg/100 g). The viable cell count was 1.2–2.8×10^4 CFU/g, which is acceptable for processed seafoods. Mercury, lead and cadmium were present only in trace amounts, while the contents of zinc and copper were around 10 ppm in shrimp muscle and about 14 ppm in shrimp by-products. Major fatty acids present were 16:0, 10:1n-9, 20:5n-3, and 22:6n-3. Total amino acid contents were in the range of 8100–10,300 mg/100 g. The by-products of shrimp had high contents of aspartic acid, glutamic acid, phenylalanine, lysine and arginine and their total protein contents were 10,300 mg/100 g in SS and 8130 mg/100 g in NPS. Taurine, threonine, leucine, tryrosine and phenylalanine were the predominant free amino acids in shrimp processing by-products. Calcium (3000 mg/100 g), phosphorus (400 mg/100 g), sodium (270 mg/100 g) and magnesium (100 mg/100 g) were the predominant minerals present, while manganese and iron were present in trace amounts. The total content of ATP related compounds of shrimp by-products was 330 mg/100 g. Thus, shrimp processing by-products may serve as a useful source of protein and flavorants in food fomulations.

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