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Comparative studies on chemical composition and thermal properties of black tiger shrimp (*Penaeus monodon*) and white shrimp (*Penaeus vannamei*) meats

Pisal Sriket [a], Soottawat Benjakul [a,*], Wonnop Visessanguan [b], Kongkarn Kijroongrojana [a]

[a] *Department of Food Technology, Faculty of Agro-Industry, Prince of Songkla University, 15 Kanchanawanich Road, Hat Yai, Songkhla 90112, Thailand*
[b] *National Center for Genetic Engineering and Biotechnology, National Science and Technology Development Agency, 113 Phaholyothin Road, Klong 1, Klong Luang, Pathumthani 12120, Thailand*

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Abstract

Chemical composition and thermal properties of meat from two species of shrimps, black tiger shrimp (*Penaeus monodon*) and white shrimp (*Penaeus vannamei*), were comparatively studied. White shrimp meat had higher protein and ash contents than had black tiger shrimp meat ($p < 0.05$). Fractionation of nitrogenous constituents revealed that myofibrillar protein was the major component in the muscles; myosin heavy chain (MHC) and actin were the predominant proteins. White shrimp meat comprised higher stromal protein with greater pepsin-soluble collagen and insoluble collagen contents than did black tiger shrimp meat. Muscle proteins from black tiger shrimp, especially MHC, had higher thermal stability than those from white shrimp as indicated by the higher transition temperature (T_{max}) as well as the lower inactivation rate constant (K_D). Phospholipid was the predominant lipid (72–74%) in both shrimps, followed by triglyceride. Polyunsaturated fatty acids were found as the major fatty acids with the range of 42.2–44.4%. DHA (22:6)/EPA (20:5) ratio in black tiger shrimp (2.15) was higher than that in white shrimp (1.05). Mg was the dominant mineral in both shrimps. Ca and Fe were also found at high concentrations. Arginine was the most abundant amino acid, while leucine, isoleucine and proline were predominant in both shrimps. Glutamic acid and glycine contents were greater in black tiger shrimp meat; however, white shrimp meat had higher hydroxyproline content. Different compositions might govern the different characteristics as well as thermal properties of both species.

Keywords: Black tiger shrimp; White shrimp; Muscle; Protein; Lipid; Composition; Mineral

1. Introduction

Seafood products have attracted considerable attention as important sources of nutrients in the human diet. Apart from their delicacy, crustacean species such as shrimp, crab and lobster, consist of amino acids, peptides, protein and other useful nutrients. Penaeid shrimps have become an economically important species for Thailand and are widely cultured in ponds. In Thailand, approximately 50 species of *Penaeus* are found (Chaitiamvong & Supongpan, 1992). Among those, black tiger shrimp (*Penaeus monodon*) and white shrimp (*Penaeus vannamei*) are commonly cultured and exported with a catch volume over 1000 tons per year and Thailand recently exported 249,570 tons of shrimp and shrimp products with the value of 2.19 billion US dollars (Suphamongkhon, 2002).

Shrimp meat is an excellent source of protein (Yanar & Celik, 2006). Additionally, shrimp muscle consists of highly unsaturated fatty acids (HUFA) such as eicosapentaenoic (20:5*n*3, EPA) and docosahexaenoic (22:6*n*3, DHA) acids, considered as essential (Feliz, Gatlin, Lawrence, & Velazquez, 2002). Shrimp meat is also a good source of minerals

* Corresponding author. Tel.: +66 7428 6334; fax: +66 7421 2889.
E-mail address: soottawat.b@psu.ac.th (S. Benjakul).

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such as calcium (Yanar & Celik, 2006). Nevertheless, the compositions can vary with feed. Feed quality, stocking density and water quality are the main factors affecting productivity for semi-intensive and intensive culture of Penaeid shrimp (Cruz-Suarez, Ricque-Marie, Martinez-Vega, & Wesche-Ebeling, 1993). Formulated feed plays an important role as the source of nutrients and the protein contents in commercial shrimp feeds vary between 30% and 50% (Martinez, Campana, & Porchas, 2003). Additionally, proximate compositions (Karakoltsidis, Zotos, & Constantinides, 1995), fatty acid profiles, cholesterol contents (Luzia, Sampaio, Castellucci, & Torres, 2003) and total carotenoid contents (Yanar, Celik, & Yanar, 2004) of shrimps change seasonally. Both black tiger shrimp and white shrimp have been accepted among consumers differently, possibly owing to their varying compositions and properties. However, little information regarding the chemical composition and thermal properties of both shrimps has been reported. The objective of this investigation was to compare the chemical compositions and thermal properties of meats of black tiger shrimp and white shrimp cultured in Thailand.

2. Materials and methods

2.1. Chemicals

Chloroform, methanol, sulfuric acid, nitric acid, isopropanol, chloramine T and ρ-dimethylamino-benzaldehyde were purchased from Merck (Darmstadt, Germany). Acrylamide, *N,N,N′,N′*-tetramethylethylenediamide (TEMED) and bis-acrylamide were obtained from Fluka (Buchs, Switzerland). Adenosine 5′-triphosphate (ATP) was procured from Sigma (St. Louis, MO, USA).

2.2. Sample preparation

Black tiger shrimp (*P. monodon*) and white shrimp (*P. vannamei*), with the size of 60 shrimps/kg, were obtained from the farms in Songkhla and Suratthani provinces, respectively. The shrimps were placed in ice with an ice/shrimp ratio of 2:1 (w/w) and transported to the Department of Food Technology, Prince of Songkla University, Hat Yai, Songkhla within approximately 1 h and 4 h, respectively. Upon the arrival, the shrimps were washed with clean water and deheaded. The shells were then peeled off. The shrimps were deveined and the edible portions were ground to obtain uniformity. The samples were placed in polyethylene bags and kept in ice during the analyses.

2.3. Chemical analysis

2.3.1. Proximate analysis

Shrimp meats of both species were analysed for moisture, ash, fat and protein contents according to the method of AOAC (1999). The values were expressed as % (wet weight basis).

2.3.2. Determination of protein and non-protein nitrogenous compounds

Non-protein nitrogenous constituents, sarcoplasmic protein, myofibrillar protein, alkali-soluble protein and stromal proteins in shrimp meats were fractionated according to the method of Hashimoto, Watabe, Kono, and Skiro (1979). Nitrogen content in each fraction was measured by the Kjeldahl method (AOAC, 1999). Protein patterns of different fractions were determined using sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS–PAGE), with 10% running gel and 4% stacking gel, as described by Laemmli (1970).

2.3.3. Determination of collagen

Collagen was isolated as two different fractions, pepsin-soluble (PSC) and insoluble (ISC) collagen fractions, according to the method of Sato, Yoshinaka, Sato, Itoh, and Shimizu (1988). Hydroxyproline content in each fraction was determined as described by Bergman and Loxley (1963). A factor of 11.42 was used to convert the amount of hydroxyproline to total collagen (Sato, Yoshinaka, Soto, & Shimizu, 1986). Protein patterns of each fraction were determined according to the method of Laemmli (1970).

2.3.4. Amino acid analysis

Samples were hydrolysed under reduced pressure in 4.0 M methanesulfonic acid containing 0.2% (v/v) 3-2 (2-aminoethyl) indole at 115 °C for 24 h. The hydrolysates were neutralised with 3.5 M NaOH and diluted with 0.2 M citrate buffer (pH 2.2). An aliquot (0.4 ml) was applied to an amino acid analyser (MLC-703; Atto Co., Tokyo, Japan).

2.3.5. Determination of lipid and fatty acid profile

Lipid in the shrimp muscle was extracted by the Bligh and Dyer method (1959). The lipid compositions were determined by thin-layer chromatography/flame ionisation detector (TLC-FID). Scanned quartz rods (silica gel powder-coated Chromarod S III) were dipped in 3% boric acid solution for 5 min, dried and rescanned with the TLC-FID analyser. The sample solution (1 μl) was spotted on the rod and the separation was carried out with the mixture of benzene: chloroform: acetic acid (52:20:0.7) for approximately 35 min. Then, the rods were dried in an oven (105 °C) for 5 min before analysing with the flame ionization detector. The analytical conditions were H_2 flow rate of 160 ml/min, air flow rate of 2000 ml/min and scanning speed of 30 s/scan. Retention time of lipid composition standards was used to identify chromatographic peaks. Peak area was quantitated and expressed as % of total lipid.

The fatty acid compositions were determined as fatty acid methyl esters (FAME) using a gas chromatography, GC-14A (Shimadzu, Kyoto, Japan) equipped with fused silica capillary column Carbowax-30 M (30 m, 0.25 mm ID) and flame ionisation detector (FID). Helium was used as the carrier gas at a flow rate of 30 cm/s. The initial

temperature of the column was set at 170 °C and was increased to 225 °C with a rate of 1 °C/min and then held at 220 °C for an additional 20 min. The detector temperature was set at 270 °C, while the temperature at the injection port was maintained at 250 °C. Retention time of FAME standards was used to identify chromatographic peaks. Peak area was quantitated and expressed as % of total lipid (AOAC, 1999).

2.3.6. Determination of mineral content

Iron (Fe), copper (Cu), manganese (Mn), cadmium (Cd), nickel (Ni), zinc (Zn), cobalt (Co), calcium (Ca) and magnesium (Mg) contents were determined by the inductively coupled plasma optical emission spectrophotometer (ICP-OES) (Perkin–Elmer, Model 4300 DV, Norwalk, CT, USA) according to the method of AOAC (1999). Ground shrimp meat (4 g) was mixed well with 4 ml of nitric acid. The mixture was heated on the hot plate until digestion was completed. The digested samples were transferred to a volumetric flask and the volume was made up to 10 ml with deionised water. The solution was subjected to (ICP-OES) analysis. Flow rates of argon to plasma, auxiliary and nebulizer were kept at 15, 0.2, and 0.8 l/min, respectively. Sample flow rate was set at 1.5 ml/min. The wavelengths for analysis of Fe, Cu, Mn, Cd, Ni, Zn, Co, Ca and Mg were 238.2, 327.4, 257.6, 228.8, 231.6, 206.2, 228.6, 317.9 and 285.2 nm, respectively. The concentration of mineral was calculated and expressed as mg/kg sample.

2.4. Determination of thermal properties

2.4.1. Differential scanning calorimetry (DSC)

Thermal transition of shrimp meat was measured using differential scanning calorimetry (DSC) (Perkin–Elmer, Model DSCM, Norwalk, CT, USA). The samples (15–20 mg wet weight) were placed in the DSC hermetic pans, assuring a good contact between the sample and the pan bottom. An empty hermetic pan was used as a reference. The samples were scanned at 10 °C/min over the range 20–100 °C. T_{max} was measured and the denaturation enthalpies (ΔH) were estimated by measuring the area under the DSC transition curve.

2.4.2. Thermal stability

Natural actomysin (NAM) was extracted according to the method of Benjakul, Seymour, Morrissey, and An (1997). NAM solution (3–5 mg/ml) was incubated at different temperatures (0, 10, 20, 30, 40, 50 and 60 °C). At definite times (0, 5, 10, 30 and 60 min), samples were taken and immediately cooled in iced water. Ca^{2+}-ATPase activity was then measured according to the method of Benjakul et al. (1997). The inactivation rate constant (K_D) was calculated as described by Tsai, Wang, and Jiang (1989) as follows:

$$K_D = (\ln C_0 - C_t)/t$$

where C_0 represents Ca^{2+} -ATPase activity before incubation; C_t, Ca^{2+} -ATPase activity after incubation for time t; and t represents incubation time (s).

2.5. Statistical analysis

Data were subjected to analysis of variance (ANOVA) and mean comparison was carried out using Duncan's multiple range test (DMRT) (Steel & Torrie, 1980). Statistical analyses were performed using the Statistical Package for Social Science (SPSS 11.0 for windows, SPSS Inc., Chicago, IL).

3. Results and discussion

3.1. Proximate composition

Both shrimps had high moisture contents (80.47 and 77.21%). Protein was found as the major constituent, indicating that shrimp meat can be a good source of amino acids. Black tiger shrimp meat had a higher moisture content (Table 1) but lower protein content than had white shrimp meat ($p < 0.05$). No differences in fat content between two species were observed ($p > 0.05$). A greater ash content was noticeable in white shrimp meat than in black tiger shrimp meat. Proximate compositions of the edible part of red shrimp, pink shrimp and lobster are slightly different (Rosa & Nunes, 2003). Differences in proximate composition might result in differences in nutritional value, sensory qualities and shelf-life of the shrimps. Proximate compositions in shrimp muscles are governed by many factors, including species, growth stage, feed and season (Karakoltsidis et al., 1995; Sikorski, Kolakowska, & Pan, 1990).

3.2. Proteins and non-protein nitrogenous compounds

Proteins and non-protein nitrogenous components in both black tiger shrimp and white shrimp meats are shown in Table 2. Myofibrillar protein constituted the major protein in both shrimps. Sarcoplasmic protein was found as the second predominant protein in the shrimp meats. The result was in agreement with Hashimoto et al. (1979) who reported that myofibrillar and sarcoplasmic proteins are the major proteins in fish muscle. From this result, white shrimp showed more myofibrillar protein, sarcoplasmic

Table 1
Proximate compositions of black tiger shrimp and white shrimp meats

Composition (% wet weight)	Black tiger shrimp	White shrimp
Moisture	80.47 ± 0.26^a	77.21 ± 0.18^b
Ash	0.95 ± 0.01^b	1.47 ± 0.10^a
Protein	17.1 ± 0.56^b	18.8 ± 0.23^a
Fat	1.23 ± 0.36^a	1.30 ± 0.09^a

Values are given as means ± SD from triplicate determinations. Different superscripts in the same row indicate significant differences ($p < 0.05$).

Table 2
Nitrogenous constituents in black tiger shrimp and white shrimp meats

Composition (mg N/g muscle)	Black tiger shrimp	White shrimp
Non-protein nitrogen	4.68 ± 0.31^{a}	1.44 ± 0.23^{b}
Sarcoplasmic protein	6.16 ± 0.02^{b}	7.81 ± 0.62^{a}
Myofibrillar protein	12.6 ± 0.35^{a}	14.3 ± 0.99^{a}
Alkali-soluble protein	0.65 ± 0.05^{a}	0.36 ± 0.03^{b}
Stromal protein	0.21 ± 0.01^{b}	2.66 ± 0.11^{a}

Values are given as means ± SD from triplicate determinations. Different superscripts in the same row indicate significant differences ($p < 0.05$).

protein and stromal proteins than did black tiger shrimp ($p < 0.05$). However, a lower alkali-soluble protein content was found in white shrimp than in black tiger shrimp ($p < 0.05$). The major fraction of stromal protein is collagen (Foegeding, Allen, & Dayton, 1986). Differences in protein compositions, especially stromal protein, might determine the quality attributes of both species. When comparing the non-protein nitrogenous components between the two species, it was noted that black tiger shrimp had a greater content than had white shrimp ($p < 0.05$). Such a difference might affect the flavour and taste of both shrimps. Non-protein nitrogenous constituents, such as free amino acids, peptides, betaine and nucleotide, play an essential role in the flavour of fish and shellfish (Sikorski et al., 1990). Generally, black tiger shrimps have been recognised to possess superior acceptability, in terms of flavour and taste, to white shrimp. This might be governed by the different amount and compositions of non-protein nitrogenous constituents.

SDS–PAGE patterns of whole meat from black tiger shrimp and white shrimp meats are shown in Fig. 1. Both shrimps had myosin heavey chain (MHC) as the dominant protein component, constituting around 56.8–64.3% of total proteins. MHC is the major protein in myofibrillar protein (Shahidi, 1994). Actin was found as the second dominant protein. In general, similar protein patterns were noticeable in the two shrimps. Nevertheless, slight differences in band intensity of proteins with MW of 84 and 66 kDa were observed. Protein patterns of different fractions of both shrimps are illustrated in Fig. 2. For the myofibrillar protein fraction, two major protein bands, corresponding to MHC and actin, were observed. Generally, low-molecular-weight proteins were found in the sarcoplasmic protein fraction. Protein with MW of 24 kDa was predominant. For the alkali fraction, smear bands with low molecular weight were found in black tiger shrimp. For the alkali fraction of white shrimp, proteins with MW of 36, 29 and 24 kDa were predominant. Similar protein patterns were noticeable in stromal fractions of both species. The differences in protein compositions might result in the different properties and characteristics between the shrimps.

3.3. Collagen

PSC and ISC from black tiger shrimp and white shrimp meats were isolated with yields of 0.36%, 0.48% and 0.83%, 3.32% (dry weight), respectively. From the results, it was found that white shrimp meat had higher PSC and ISC contents than had black tiger shrimp meat. The higher collagen content observed in white shrimp meat was coincidental with the greater stromal protein content (Table 2). Yoshinaka, Sato, Itoh, Nakajima, and Sato (1989) reported that the collagen content in the abdominal muscle of seven species, including shrimp, prawn, lobster and squilla, varied among the species ranging from 1.1% to 6.2% of total tissue protein and the content in pereiopod and thoracic muscles of four species of crab varied from 0.2% to 0.8%. A higher collagen content was associated with a firmer texture (Hatae, Tobimatsu, Takeyama, & Matsumoto, 1986; Sato et al., 1986). White shrimp meat was most likely tougher than black tiger shrimp (data not shown).

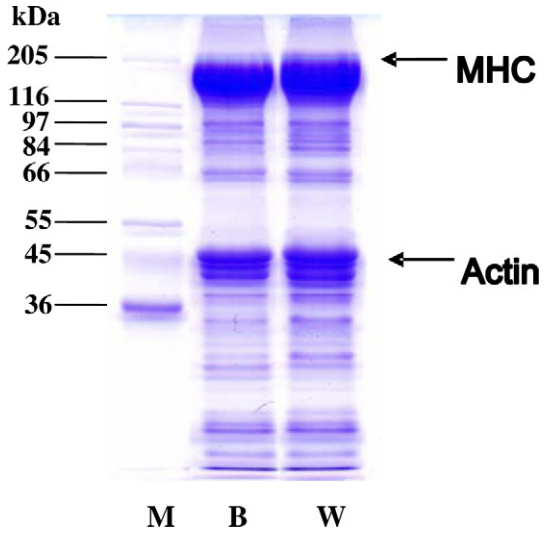

Fig. 1. Electrophoretic pattern of black tiger shrimp and white shrimp meats. M: high-molecular- weight protein marker, B: black tiger shrimp meat, W: white shrimp meat.

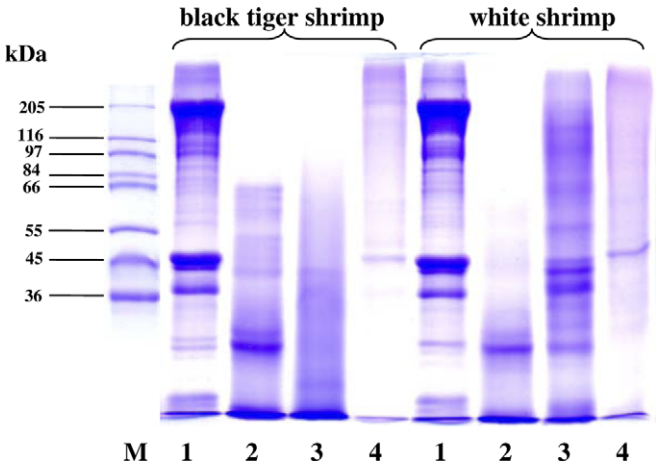

Fig. 2. Electrophoretic pattern of various protein fractions from black tiger shrimp and white shrimp meats; lanes 1, 2, 3, 4: myofibrillar, sarcoplasmic, alkali-soluble and stromal protein fractions, respectively.

The protein patterns of PSC and ISC of both shrimp meats are shown in Fig. 3. PSC from both species had patterns similar to those of porcine cartilage collagen types II and III (Fig. 3). Type II collagen consists of three chains of α1(II) and Type III collagen consists of three chains of α1(III) (Foegeding et al., 1986). Yoshinaka et al. (1989) reported that the major collagen from the crustacean muscle was similar to type V collagen from vertebrate muscle. However, the type of collagen of fish was different, depending on the species. For ISC, different protein patterns were found between the two shrimps. ISC was most likely associated with cross-linking of collagen molecules, and may have an influence on the texture of shrimp meat. Few cross-links indicate a low shear strength (Montero & Borderias, 1990). The gaping score in fish samples correlates with the amount of insoluble collagen, the greater the ISC, the less gaping (Espe et al., 2004). The distribution of soluble and insoluble collagen in fish muscle varies from species to species (Eckhoff, Aidos, Hemre, & Lie, 1998).

3.4. Amino acid compositions

The amino acid compositions of black tiger shrimp and white shrimp meats are shown in Table 3. Amino acids were different between species. Yanar and Celik (2006) also reported different amino acid compositions between green tiger shrimp (*Penaeus semisulcatus* De Haan, 1844) and speckled shrimp (*Metapenaeus monoceros* Fabricus, 1789). From the results, it was found that most abundant amino acid in both species was arginine. Proline, leucine, isoleucine, phenylalanine and glutamic acid were abundant in both species. These amino acids constituted more than 50% of the total amino acids. A high content of free arginine in crustaceans enriches the sweet taste and yields a seafood-like flavour (Sikorski et al., 1990). Glycine, alanine, serine and threonine taste sweet, while arginine, leucine, valine, methionine, phenylalanine, histidine and isoleucine give bitter taste (Sikorski et al., 1990). Alanine, proline and serine contribute to the acceptability of prawns and lobsters (Fuke, 1994). A higher glycine content was found in black tiger shrimp (3.10%) than in white shrimp (2.99%). The sweetness of fresh prawn and crab is attributed to the abundance of free glycine in their muscle (Sikorski et al., 1990). From the results, black tiger shrimp meat had higher contents of arginine, phenylalanine, isoleucine and glutamic acid, but lower contents of aspartic acid, proline and leucine than had white shrimp meat. Apart from amino acids, the nucleotides and quaternary ammonium compounds are the major contributors to the taste of seafoods (Sikorski et al., 1990). AMP and ATP are the dominating nucleotides in crustaceans and mollusks, immediately post-mortem (Mendes, Quinta, & Nunes, 2001).

Black tiger shrimp and white shrimp contained 9.70% and 13.3% of proline, respectively. Proline showed an important adjustment necessary for osmoregulation, following changes in osmotic stress (Bishop & Burton, 1993). Hydroxyproline content was higher in white shrimp meat than in black tiger shrimp meat. This was coincidental with the higher stromal protein content in the former (Table 2). The ratios of essential amino acids (EAA) to nonessential amino acids (NEAA) in black tiger shrimp and white shrimp were 0.70 and 0.67, respectively. Iwasaki and Harada (1985) explained

Table 3
Amino acid compositions of black tiger shrimp and white shrimp (mg/100 g muscle tissue)

Amino acids	Black tiger shrimp	White shrimp
Aspartic acid + asparagine	1456	1704
Hydroxyproline	69.8	215
Threonine	1213	1129
Serine	1069	1027
Glutamic acid + glutamine	1854	1504
Proline	2889	3862
Glycine	1182	871
Alanine	1525	1601
Cysteine	528	547
Valine	1159	1078
Methionine	1396	1298
Isoleucine	2586	2411
Leucine	2974	3153
Tyrosine	1956	1967
Phenylalanine	2277	1967
Hydroxylysine	82.4	–
Lysine	654	630
Histidine	667	666
Arginine	4273	3494
Total	29 808	29 121

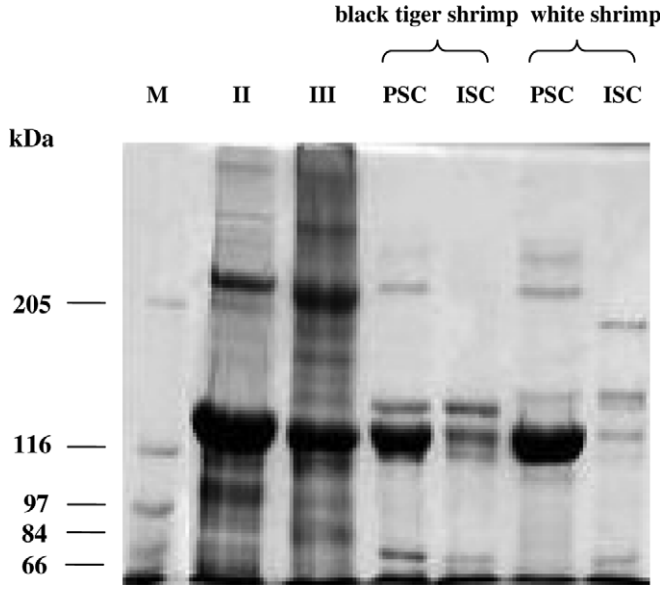

Fig. 3. Electrophoretic pattern of PSC and ISC from black tiger shrimp and white shrimp meats; M; protein markers I and II: porcine cartilage collagen type II and III, respectively. PSC: pepsin-soluble collagen; ISC: insoluble collagen.

that the EAA/NEAA ratio of many fish species is 0.70 on average, whereas this ratio was reported to be 0.59 in crab (*Portunus trituberculatus*) and squid (*Doryteus-this bleekeri*). Thus, the different amino acids might be associated with the varying tastes as well as textural properties of meat of the two shrimps.

3.5. Lipid composition and fatty acid profile of shrimp meat

Lipids from both shrimp meats had phospholipids as the major component (72–74%), followed by triglyceride (Table 4). Therefore, most lipids in shrimp meat might be membrane lipids with high phospholipid contents. Takama, Suzuki, Yoshida, Hirofumi, and Mitsui (1999) reported that phospholipids were the major lipid in fish muscle. The higher free fatty acid content, with coincidental lower diglyceride content in white shrimp, than in black tiger shrimp, suggested that lipid from white shrimp would be more susceptible to hydrolysis caused by lipase or phospholipase. Lipase and phospholipase in shrimp muscle play an important role in hydrolysis of lipid (Lopez & Maragoni, 2000).

The fatty acid profiles of black tiger shrimp and white shrimp meats are shown in Table 5. PUFAs were found as the major fatty acids with the range of 42.2–44.4%. This result was in agreement with Lin, Huang, and Huang (2003) who found that PUFAs were the major fatty acids in white shrimp. The contents of $n-3$ PUFA in both shrimps were 1.14-fold greater than those of $n-6$ PUFA. C22:6 $n-3$(DHA) and 20:5 $n-3$(EPA) were the dominant PUFAs in lipid from both shrimps. DHA and EPA were found at levels of 14.9 and 8.58% in the lipid from black tiger shrimp and 9.99 and 9.46% in the lipid from white shrimp. DHA/EPA ratio in black tiger shrimp meat (2.15) was higher than that found in white shrimp meat (1.05). White shrimp meat had higher oleic acid (C18:1), linoleic acid (C18:2) and linolenic acid (C18:3) contents than had black tiger shrimp meat. Among the saturated fatty acids, C16:0 and C18:0 were the most abundant fatty acids in the lipid extracted from black tiger shrimp and white shrimp. Rosa and Nunes (2003) and Yanar and Celik (2005) reported that palmitic acid (C16:0), stearic acid (C18:0), DHA and EPA were the most abundant fatty acids in shrimps (*Nephrops norvegicus*, *Parapenaeus longirostris*, *Aristeus antennatus* and *Penaeus semisulcatus, Metapenaeus monoceros*).

Table 4
Lipid compositions of black tiger shrimp and white shrimp meats

Composition (% dry weight)	Black tiger shrimp	White shrimp
Phospholipid	74.5 ± 0.02^{a}	72.3 ± 2.27^{a}
Triglyceride	16.3 ± 0.01^{a}	16.2 ± 0.06^{b}
Diglyceride	6.70 ± 0.29^{a}	2.71 ± 0.01^{b}
Free fatty acid	2.46 ± 0.16^{b}	8.77 ± 0.07^{a}

Values are given as means ± SD from triplicate determinations. Different superscripts in the same row indicate significant differences ($p < 0.05$).

Table 5
Fatty acid compositions (g/100 g) of black tiger shrimp and white shrimp meats

Fatty acids	Black tiger shrimp	White shrimp
Myristic acid C14:0	0.38	0.41
Pentadecanoic acid C15:0	0.38	0.37
Palmitic acid C16:0	22.2	21.8
Palmitoleic acid C16:1 $n-7$	1.42	1.39
Heptadcanoic acid C17:0	1.53	1.45
Cis-10-Heptadecenoic acid C17:1	0.31	0.24
Stearic acid C18:0	10.51	11.5
Oleic acid C18:1 $n-9$	9.94	11.4
Cis-Vaccenic acid C18:1 $n-7$	2.18	2.41
Linoleic acid C18:2 $n-6$	13.0	15.6
α-Linolenic acid C18:3 $n-3$	0.77	0.98
ϒ-Linolenic acid C18:3 $n-6$	0.25	0.30
Arachidic acid C20:0	0.15	0.23
Cis-11-Eicosenoic acid C20:1 $n-9$	0.4	0.53
Cis-11-Eicosenoic acid C20:1 $n-11$	0.18	0.16
Cis-11,14-Eicosadienoic acid C20:2 $n-6$	0.68	1.40
Cis-11,14,17-Eicosatrienoic acid C20:3 $n-3$	0.12	0.18
Arachidonic acid C20:4 $n-6$	4.55	3.23
Eicosatetraenoic acid C20:4 $n-3$	0.15	–
Cis-5,8,11,14,17-Eicosapentaenoic acid C20:5 $n-3$ (EPA)	8.58	9.46
Behenic acid C22:0	0.18	–
Docosatetraenoic acid C22:4 $n-6$	0.21	0.20
Docosapentaenoic acid C22:5 $n-3$	0.60	0.50
Docosapentaenoic acid C22:5 $n-6$	0.69	0.34
Cis-4,7,10,13,16,19-docosahexaenoic acid C22-6 $n-3$ (DHA)	14.9	9.99
Lignoceric acid C24:0	0.14	–
Nervonic acid C24:1	0.22	–
Unidentified peak	5.50	5.94
PUFA	44.3	42.2
*n*3 PUFA	25.1	21.1
*n*6 PUFA	19.3	21.1
SFA	35.4	35.8

PUFA: polyunsaturated fatty acids; SFA: saturated fatty acids.

3.6. Mineral content of shrimp meat

The contents of different minerals in the meats of both shrimps, black tiger shrimp and white shrimp, are shown in Table 6. Black tiger shrimp meat had higher contents of all minerals determined than had white shrimp meat.

Table 6
Mineral contents in black tiger shrimp and white shrimp meats

Mineral content (mg/kg)	Black tiger shrimp	White shrimp
Fe	30.7 ± 0.19	12.2 ± 0.42
Cu	6.31 ± 0.02	4.07 ± 0.16
Mn	1.00 ± 0.00	0.48 ± 0.00
Cd	ND	ND
Ni	0.60 ± 0.02	0.36 ± 0.01
Zn	17.3 ± 0.09	14.7 ± 0.56
Co	ND	ND
Ca	259 ± 0.62	247 ± 4.99
Mg	431 ± 3.10	361 ± 8.15

Values are given as means ± SD from triplicate determinations.
ND: Not detectable.

Table 7
T_{max} and enthalpy of muscle proteins of black tiger shrimp and white shrimp meats

Species	T_{max} I (°C)	ΔH (j/g)	T_{max} II (°C)	ΔH (j/g)
Black tiger shrimp	51.28 ± 0.56^{a}	1.46 ± 0.06^{a}	66.20 ± 0.28^{b}	0.66 ± 0.07^{a}
White shrimp	50.13 ± 0.14^{a}	1.40 ± 0.03^{a}	71.17 ± 0.34^{a}	0.67 ± 0.10^{a}

Values are given as means ± SD from triplicate determinations. Different superscripts in the same column indicate significant differences ($p < 0.05$).

From the results, it was found that Mg was the dominant mineral in both shrimp meats. Ca and Fe were also found at high levels. Ca is essential for hard tissue structure, blood clotting, muscle contraction, nerve transmission, osmoregulation and as a cofactor for enzymatic procession (Lovell, 1989). Transition metal ions, particularly Cu and Fe, have been known as the major catalysts for oxidation (Thanonkaew, Benjakul, & Visessanguan, 2006). Cu ion is found in hemocyanin, a pigment in the blood of crustaceans (Decker & Tuczek, 2000). Those minerals might contribute to the oxidation of shrimp muscle during handling, processing and storage. Castell, Maclean, and Moore (1965) found that the relative prooxidant activity of ions in fish muscle decreased in the order: $Cu^{2+} > Fe^{2+} > Co^{2+} > Cd^{2+} > Li > Ni^{2+} > Mg^{2+} > Zn^{2+} > Ca^{2+} > Ba^{2+}$. Owing to a higher content of metal ions, black tiger shrimp meat might be more susceptible to lipid oxidation than white shrimp meat. Additionally, higher contents of PUFAs in black tiger shrimp, especially DHA, might cause the meat to be more prone to oxidation. Major sources of minerals for marine organisms are sea water and feed (Ichihashi, Kohno, Kannan, Tsumura, & Yamasaki, 2001). No cadmium or cobalt was detectable in either shrimp meat.

3.7. Thermal stability of shrimp muscle proteins

Thermal transitions of shrimps muscle proteins were determined using DSC. T_{max} and ΔH are shown in Table 7. DSC analysis was used to determine the thermal transition or unfolding temperature of protein and also to quantify the enthalpy of conformational transition (John & Shashtri, 1998). Two major peaks were obtained, corresponding to myosin and actin peaks. The two shrimps had similar T_{max} and enthalpy values of the first peak, suggesting that myosins of both shrimp muscles had similar temperatures and energies required for denaturation. T_{max} of the second peak, representing actin of black tiger shrimp, was lower than that of white shrimp. However, no differences in the enthalpy of actin were found between the two species ($p > 0.05$). Poulter, Ledward, Godber, Hall, and Rowlands (1985) reported that T_{max} values of the first and the second peak of fish were 41.70–52.70 and 72.6–73.8 °C, respectively. This result revealed that the actin of white shrimp meat was more likely to resist thermal denaturation than was black tiger shrimp meat.

The inactivation rate constants (K_D value) of natural actomyosins (NAM) from both shrimps are shown in Table 8. Slight increases in K_D values were noticeable at temperature below 20 °C. Substantial increases in K_D value were observed at temperature ranges of 30–40 °C. At the same temperature, NAM from white shrimp had a slightly higher K_D value than NAM from black tiger shrimp. From the results, it was presumed that muscle proteins, particularly MHC, of white shrimp were more susceptible to thermal denaturation than were those of black tiger shrimp. MHC has been reported to possess Ca^{2+}-ATPase activity, which can be used as an indicator of MHC integrity (Benjakul et al., 1997). Actin was suggested to play a protective role in the stability of myosin (Jiang, Wang, & Chen, 1989). Thus, the stability of muscle protein from black tiger shrimp was slightly higher than that from white shrimp. The differences in thermal stability between the two species possibly resulted from the different intrinsic properties, amino acid composition and actin/myosin ratio.

4. Conclusion

Meats of black tiger shrimp and white shrimp are a good source of protein and polyunsaturated fatty acids. However, chemical composition varied with species. White shrimp had a higher connective tissue content than had black tiger shrimp. Thermal stability of muscle proteins was different between species. The differences in chemical compositions and thermal properties between species might be associated with the different characteristics of the shrimps.

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Table 8
Thermal inactivation rate constant ($K_D \times 10^{-5}$ s^{-1}) of natural actomyosin from black tiger shrimp and white shrimp meats

Species	Temperature (°C)				
	0	10	20	30	40
Black tiger shrimps	0.09 ± 0.01^{aE}	3.14 ± 0.22^{aD}	5.48 ± 0.39^{bC}	40.9 ± 2.31^{aB}	59.1 ± 0.28^{aA}
White shrimps	0.10 ± 0.02^{aE}	3.21 ± 0.74^{aD}	8.46 ± 1.86^{aC}	42.5 ± 1.45^{aB}	62.5 ± 2.24^{aA}

Values are given as means ± SD from triplicate determinations. Different superscripts in the same column indicate significant differences ($p < 0.05$). Different capital superscripts in the same row indicate significant differences ($p < 0.05$).

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