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Comparison of Lipid Content and Fatty Acid Composition in the Edible Meat of Wild and Cultured Freshwater and Marine Fish and Shrimps from China

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ABSTRACT: The lipid content and fatty acid composition in the edible meat of twenty-nine species of wild and cultured freshwater and marine fish and shrimps were investigated. Both the lipid content and fatty acid composition of the species were specified due to their unique food habits and trophic levels. Most of the marine fish demonstrated higher lipid content than the freshwater fish, whereas shrimps had the lowest lipid content. All the marine fish and shrimps had much higher total n-3 PUFA than n-6 PUFA, while most of the freshwater fish and shrimps demonstrated much lower total n-3 PUFA than n-6 PUFA. This may be the biggest difference in fatty acid composition between marine and freshwater species. The cultured freshwater fish demonstrated higher percentages of total PUFA, total n-3 PUFA, and EPA + DHA than the wild freshwater fish. Two freshwater fish, including bighead carp and silver carp, are comparable to the marine fish as sources of n-3 PUFA.

KEYWORDS: lipid content, fatty acid composition, marine fish, freshwater fish, shrimp

INTRODUCTION

China has been the world's leading fishery producer since 1989. According to the China Fisheries Yearbook, the total fishery production in China was about 47 million tonnes in 2007 (25 million tonnes of marine and 22 million tonnes of freshwater aquatic productions) and occupied about 33% of the total world fisheries.[1] Among the aquatic products, 92.26% of the marine fish harvested in China are wild fish (8.22 in 8.91 million tonnes). These wild marine fish are mainly captured in fishing grounds of the East China Sea, South China Sea, Bohai Sea, and Yellow Sea, and consumed worldwide, especially in the coastal areas.[1] However, 91.75% of the freshwater fish are cultured fish (17.51 in 19.08 million tonnes). They are cultured in reservoirs, ponds, and rice fields, and consumed nationwide, especially in the inland areas.[1] As for shrimps, 34.30% of the marine species (0.71 in 2.07 million tonnes) and 82.67% of the freshwater species (1.67 in 2.02 million tonnes) are cultured shrimps.[1] The marine fish used in this study were from Zhoushan fishing ground in the East China Sea (the biggest fishing ground in China), while the freshwater fish and shrimps were obtained from the markets or from the local fisherman in Zhejiang province (one of the largest fish producers in China).

Fish are known to be rich in n-3 polyunsaturated fatty acids (PUFA), especially eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3).[2,3] These fatty acids have been demonstrated to be very important for human health. Horrocks and Yeo[4] concluded that DHA is essential for the growth and functional development of the brain in infants and is also required for maintenance of normal brain function in adults. DHA and EPA also provide health benefits by lowering serum triacylglycerol levels, increasing membrane fluidity, and reducing thrombosis.[5] Many studies have demonstrated that consumption of fish oil rich in n-3 PUFA has beneficial effects on coronary heart disease,[6] hypertension,[7] inflammation and autoimmune disorders.[8]

Generally, when fish is suggested as a means of improving health, both the lipid content and fatty acid composition must be considered. However, the lipid content and fatty acid composition of fish can be influenced by many factors, such as species, sex, size, place of capture, water temperature, feeding, and season.[2,9] Therefore, more attention should be paid to both the lipid content and fatty acid composition of different species when selecting fish for diets. Unfortunately, there is little information on the lipid content and fatty acid composition of fish species captured in China. Up to now, only one study has been conducted on the lipid components of several freshwater fish available in Shanghai, China.[10] It is because of this lack of background information that we have decided to analyze the lipid content and fatty acid composition of 29 species of common fish and shrimps (including 10 freshwater and 12 marine fishes, 2 freshwater and 5 marine shrimps), which originated from Zhejiang province, one of the largest fish producers in China. The selected freshwater fish, marine fish, and shrimps used in the present study account for approximately 90% of the total freshwater fish production, 50% of the total marine fish production, and 80% of the total shrimp production in China, respectively.[1,11] The data of this study may be of interest and useful for both fish production and consumption.

MATERIALS AND METHODS

Sample Collection and Preparation. The samples of fish and shrimps examined for lipid content and fatty acid composition in this study are shown in Table 1. All the wild marine fish, which were caught from the Zhoushan fishing ground in the East China Sea, were collected from the local fish markets during November−December (largest

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Table 1. Biometric and Biologic Characteristics, and Lipid Contents[a] in the Edible Meat of Marine Fish, Freshwater Fish, and Shrimps

		habitat[d]								
common name	scientific name	environment	climate	water depth (m)	food habit[d]	main food souces[d]	trophic level	body length (cm)	body wt (g)	lipid content (g/100 g)
				Marine Fish[b]						
white herring	*Ilisha elongata*	pelagic-neritic	tropical	>5	carnivorous	zooplankton, benthic invertebrate, small fish	3.79	32	275	6.88 ± 0.43
largehead hairtail	*Trichiurus japonicus*	benthopelagic	subtropical	100−350	carnivorous	small fish, crustaceans	4.45	70	210	7.33 ± 0.59
melon seed	*Psenopsis anomala*	benthopelagic	tropical	50−90	omnivorous	phytoplankton, zooplankton, zoobenthos	3.31	24	176	6.14 ± 0.37
chub mackerel	*Pneumatophorus japonicus*	pelagic-neritic	tropical	20−90	omnivorous	phytoplankton (diatoms), zooplankton	3.19	36	265	7.83 ± 0.51
white Chinese croaker	*Argyrosomus argentatus*	benthopelagic	temperate	40−100	carnivorous	zooplankton, benthic invertebrate	3.47	25	300	6.26 ± 0.25
spotted maigre	*Nibea albiflora*	benthopelagic	temperate	25−80	carnivorous	small fish, benthic invertebrate	3.50	34	512	7.14 ± 0.66
bluefin leather jacket	*Navodon septentrionalis*	demersal	temperate	50−120	carnivorous	benthic invertebrate, crustaceans	3.70	49	1074	0.58 ± 0.04
small yellow croaker	*Larimichthys polyactis*	benthopelagic	subtropical	60−120	carnivorous	zooplankton, zoobenthos, small fish	3.64	19	70	2.67 ± 0.18
pike eel	*Muraenesox cinereus*	demersal	subtropical	<300	carnivorous	small bottom fish, crustaceans	4.07	86	1430	5.36 ± 0.34
bombay duck	*Harpadon nehereus*	benthopelagic	tropical	>50	carnivorous	nekton, small fish	4.20	22	71	1.64 ± 0.12
Spanish mackerel	*Scomberomorus maculatus*	pelagic-neritic	tropical	10−70	carnivorous	nekton, small fish, crustaceans (shrimp)	4.50	41	443	3.37 ± 0.16
Chinese silver pomfret	*Pampus chinensis*	benthopelagic	tropical	>10	carnivorous	zooplankton, zoobenthos, crustaceans	3.60	23	184	6.06 ± 0.28
				Freshwater Fish						
crucian carp (wild)	*Carassius carassius*	demersal	temperate	>5	omnivorous	plankton, benthic invertebrate, plant materials	3.11	20	250	6.02 ± 0.52
crucian carp (cultured)	*Carassius carassius*	demersal	temperate	>5	omnivorous	plankton, benthic invertebrate, plant materials	3.11	29	470	3.60 ± 0.17
Chinese perch (wild)	*Siniperca chuatsi*	benthopelagic	temperate	>10	carnivorous	nekton, small fish	4.50	22	285	4.47 ± 0.43
Chinese perch (cultured)	*Siniperca chuatsi*	benthopelagic	temperate	>10	carnivorous	nekton, small fish	4.50	27	477	5.13 ± 0.22
snakehead (wild)	*Channa argus*	benthopelagic	temperate	<20	carnivorous	nekton, small fish, shrimps, frogs,	4.20	36	490	3.25 ± 0.30
snakehead (cultured)	*Channa argus*	benthopelagic	temperate	<20	carnivorous	nekton, small fish, shrimps, frogs,	4.20	39	660	1.93 ± 0.08
bighead carp (wild)	*Aristichthys nobilis*	benthopelagic	temperate	>5	omnivorous	phytoplankton, zooplankton	2.33	44	1550	3.21 ± 0.25
bighead carp (cultured)	*Aristichthys nobilis*	benthopelagic	temperate	>5	omnivorous	phytoplankton, zooplankton	2.33	50	2270	1.77 ± 0.11
grass carp (cultured)	*Ctenopharyngodon idella*	demersal	subtropical	<30	planktivorous	aquactic plants, submerged grasses, vegetables	2.00	51	1800	5.03 ± 0.22
common carp (cultured)	*Cyprinus carpio*	benthopelagic	subtropical	<20	omnivorous	benthic organism, plant materials	2.36	38	1220	5.35 ± 0.35
black carp (cultured)	*Mylopharyngodon piceus*	demersal	subtropical	5−30	carnivorous	small snails, clams, molluscs	3.19	67	3100	7.43 ± 0.37
silver carp (cultured)	*Hypophthalmichthys molitrix*	benthopelagic	subtropical	<20	omnivorous	phytoplankton, zooplankton	2.00	47	1680	5.36 ± 0.26
swamp eel (cultured)	*Monopterus albus*	demersal	tropical	>3	carnivorous	worms, small crustaceans, small aquatic animals	3.38	56	206	1.71 ± 0.04
Oriental weatherfish (cultured)	*Misgurnus anguillicaudatus*	demersal	subtropical	>5	carnivorous	worms, small crustaceans, small aquatic animals	3.24	15	42	2.37 ± 0.13
				Shrimps[c]						
whiteleg shrimp (marine)	*Penaeus vannamei*							10.5	15.3	1.32 ± 0.05
giant freshwater prawn (freshwater)	*Macrobrachium rosenbergii*							13.8	41.4	1.86 ± 0.08
ridgetail white prawn (marine)	*Exopalaemon carinicauda*							6.1	6.7	0.46 ± 0.03
fleshy prawn (marine)	*Fenneropenaeus chinensis*							13.2	34.2	1.18 ± 0.08
Oriental river shrimp (freshwater)	*Macrobrachium nipponense*							5.8	4.5	1.33 ± 0.10
Cipango prawn (marine)	*Exopalaemon annandalei*							4.3	2.8	1.78 ± 0.12
mantis shrimp (marine)	*Oratosquilla oratoria*							10.4	28.1	1.42 ± 0.09

[a] Results of lipid content are presented as mean ± SD (n = 5). [b] All marine fish are wild fish. [c] All shrimps are cultured shrimps. [d] All data were obtained from www.fishbase.org.

fishing season in which more than 50% of total annual marine fish are captured) in 2006. All the cultured shrimps and freshwater fish were purchased from the supermarkets in Hangzhou. Four wild freshwater fish, including crucian carp, bighead carp, snakehead and Chinese perch, which were captured from the Qiantang River, were provided by the local fishermen.

After collection, all wild marine fish were transported intraday under refrigeration (4 °C) to the Department of Food Science and Nutrition in Zhejiang University, China, whereas the cultured shrimps and freshwater fish were kept alive and transported to the department in two hours. Upon arrival, each individual of fish and shrimp samples was immediately weighed, beheaded, and dressed (for fish) or decarapaced (for shrimps), and the muscle tissue (edible muscle) was filleted (for fish only), minced, blended, and immediately stored at −80 °C until the analysis of lipid content and fatty acid composition in two weeks. For freshwater and marine fish (weight above 150 g per fish), five individuals ($n = 5$) of each species were taken for analysis. For shrimps and other fish (weight below 150 g per fish), five subsets (200 g, $n = 5$) of each species were taken for analysis.

Lipid and Fatty Acid Analysis. The total lipids of minced fish fillets (30 g each) were extracted with a chloroform−methanol (2:1, v/v) solvent system containing 10 mg/L of butylated−hydroxytoluene (BHT, Sigma Chemical Co., St. Louis, MO, USA) according to the method of Folch et al.[12] Total lipid contents were determined by gravimetric analysis.

Fatty acids were determined by gas−liquid chromatography (GLC).[13] The extraction of the total lipids from minced fish fillets (5 g each) was the same as described above. The methyl esters of the fatty acids from the lipid extract were transesterified with H_2SO_4 in methanol (5%, v/v), together with toluene, in sealed tubes at 70 °C for 2 h. The derived fatty acid methyl esters (FAME) were analyzed by using Shimadzu GC-14C (Shimadzu Corporation, Japan) fitted with a flame ionization detector (FID) and a 60 m × 0.25 mm (i.d.) × 0.25 μm (film thickness) fused silica bonded phase column (DB-23, Aglient Corporation, USA). Nitrogen was the carrier gas at the pressure of 300 kPa. The injector and detector temperature were both 270 °C. The column temperature was programmed from 150 to 180 °C at a rate of 10 °C/min, with initial hold time of 2 min; the temperature was then further increased to 215 at 2.5 °C/min and held for 6 min; finally, it was increased to 230 at 10 °C/min and held for another 5 min. Fatty acids were identified by comparison of retention time with standard mixtures of fatty acid methyl ester (Nu-Chek Prep, Inc., Elysian, MN, USA). Quantification of the fatty acid compositions were achieved by the comparison of peak areas with internal standard (nonadecanoic acid, Sigma, St. Louis, MO, USA) which was added to the samples (1 mg of internal standard in 500 mg sample) prior to extraction. The composition of fatty acids was expressed in relative percentage of the total fatty acids according to their peak areas.

Statistical Analysis. All data are presented as the mean ± standard deviation (SD). Comparisons of lipid content and fatty acid composition among marine fish, freshwater fish and shrimps were done by one-way analysis of variance (ANOVA). The Tukey−Kramer multiple comparison tests were used to test for differences between means at the 5% significance level ($P < 0.05$). Before statistical analyses, data were checked for normal distribution and variance homogeneity. Whenever these assumptions were violated, before statistical analyses, data were transformed (arcsine of the square root) to ensure normality (percentage data) or log 10 transformed to ensure homogeneity of variances. In most cases, after these transformations, both assumptions were satisfied. Multivariate analyses, including classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by nonmetric multidimensional scaling (NMDS),[14] were used to compare the fatty acid composition of each specimen. The Bray−Curtis measure of similarity was used as the basis for both classification and ordination. Statistical analyses were performed by using SPSS 16.0 and Primer Version 5.0 (Plymouth Routines in Multivariate Ecological Research, Plymouth, U.K.) for Windows.

■ RESULTS AND DISCUSSION

Lipid Content. Table 1 shows the lipid content in the edible meat of freshwater fish, marine fish, and shrimps. The lipid content of marine fish varied from 0.58 g/100 g in bluefin leather jacket to 7.83 g/100 g in chub mackerel. Such lipid contents were higher than those of Queensland marine fish in Australia (0.50−4.98 g/100 g),[15] but lower than those of marine fish (1.4−18.8 g/100 g) from the southeast coast of Brazil.[16] The lipid content of freshwater fish ranged from 1.71 g/100 g in swamp eel to 7.43 g/100 g in black carp. These lipid contents were higher than those of Turkish freshwater fish (0.39−3.21 g/100 g).[2] Rahman et al.[16] reported much wider lipid contents (1.25−34.00 g/100 g) in Malaysian freshwater fish compared with those in the present study. It was reported that the lipid content of fish changed due to species, diet, gender, geographical origin, and season.[2,17,18] All the studied shrimps displayed low lipid contents, ranging from 0.46 g/100 g in ridgetail white prawn to 1.86 g/100 g in giant freshwater prawn. Krzynowek and Panunzio[19] studied 11 species of shrimps and found lipid values in the 0.8−1.1 g/100 g range, classifying crustaceans as low-lipid foods. Similar lipid contents (0.97−1.15 g/100 g) have been also found in wild marine shrimps from the Eastern Mediterranean Sea.[20]

Fish are often classified as lean fish (lipid content <5%), medium fat fish (5−10%), and fatty fish (>10%) on the basis of their fat content.[21] Based on this classification, most of the marine fish (8 in 12) studied were medium fat fish, while most of the freshwater fish (9 in 14) were lean fish. No fatty fish were found during the study period. It seemed that most marine fish had higher lipid content than freshwater fish. Similar results have been found by Özogul et al.[2] in the fish originating from Turkey. In the present study, shrimps demonstrated much lower lipid contents than the marine and freshwater fish. This is similar to the lipid contents of fish and invertebrates in Prince William Sound, Alaska, of the United States.[22]

Fatty Acid Composition of Marine Fish. The fatty acid composition in the edible meat of 12 marine fish species are presented in Table 2. The changes in fatty acid profiles of marine fish species in terms of total and individual saturated (SFA) and unsaturated fatty acids were significant ($P < 0.05$). The levels of total PUFA, which varied from 16.1% of total fatty acids in white Chinese croaker to 41.1% in melon seed, were similar to those of total monounsaturated fatty acids (MUFA, 21.7−37.6%) but slightly lower than those of total SFA (30.1−40.6%) in most of studied marine fish species. Such results were opposite to Brazilian marine fish, in which the levels of total PUFA (27.4−49.2%) were higher than SFA (21.1−39.6%).[3] Bayır et al.[23] also found higher PUFA than SFA in marine fish from Turkish waters. This may be due to the different geographical origin and diets in the seawater, which were considered as major factors that influence the fatty acid composition of fish.[15,24,25]

Palmitic acid (16:0), accounting for more than half of the total SFA, was the predominant SFA in all the studied marine fish. This is in agreement with the previous studies on marine fish from other regions.[3,15] Stearic acid (18:0), although in a much lesser proportion than 16:0, made another important contribution to the SFA. Palmitoleic (16:1n-7) and oleic acid (18:1n-9) dominated the MUFA fraction in all marine fish, and this is similar to the marine fish from other sites.[23] In this study, all marine fish demonstrated low levels of total n-6 PUFA (1.4−5.9% of total fatty acids), but high levels of total n-3 PUFA (14.9−35.2%) and n-3/n-6 ratio (5.32−17.06). This is in accordance

Table 2. Fatty Acid Composition (% of Total Fatty Acids) in the Edible Meat of Marine Fish[a]

fatty acid	white herring	largehead hairtail	melon seed	chub mackerel	white Chinese croaker	spotted maigre	bluefin leather jacket	small yellow croaker	pike eel	bombay duck	spanish mackerel	Chinese silver pomfret	P-value
14:0	2.9 ± 0.3 e	4.3 ± 0.2 b	3.9 ± 0.2 c	3.5 ± 0.2 cd	2.2 ± 0.2 f	2.0 ± 0.1 f	1.2 ± 0.2 g	2.3 ± 0.2 f	5.1 ± 0.3 a	4.4 ± 0.3 b	4.3 ± 0.4 b	3.2 ± 0.3 de	0.000
15:0	0.4 ± 0.1 cd	0.6 ± 0.0 b	0.9 ± 0.1 a	0.5 ± 0.0 c	0.5 ± 0.0 c	0.4 ± 0.1 cd	0.4 ± 0.0 d	0.4 ± 0.0 d	0.5 ± 0.0 c	0.7 ± 0.1 b	0.5 ± 0.0 c	0.5 ± 0.0 c	0.000
15:1	0.6 ± 0.2 a	0.3 ± 0.0 b	0.6 ± 0.1 a	nd	nd	nd	nd	nd	nd	nd	nd	0.2 ± 0.0 c	0.000
16:0	21.8 ± 0.9 def	21.4 ± 1.6 def	16.6 ± 1.1 g	19.8 ± 0.9 f	28.4 ± 1.2 a	23.8 ± 0.9 cd	22.4 ± 1.6 de	27.2 ± 1.3 ab	23.6 ± 1.5 cd	25.3 ± 1.4 bc	20.1 ± 1.4 ef	20.9 ± 1.4 ef	0.000
16:1n-7	4.2 ± 0.1 g	5.3 ± 0.3 f	3.3 ± 0.4 h	5.9 ± 0.4 ef	18.4 ± 0.9 a	10.6 ± 0.7 b	3.6 ± 0.3 gh	11.3 ± 0.8 b	7.7 ± 0.5 c	6.8 ± 0.5 de	7.4 ± 0.6 cd	4.1 ± 0.4 gh	0.000
16:1n-9	0.5 ± 0.0 d	0.9 ± 0.1 b	0.3 ± 0.0 e	0.7 ± 0.0 c	0.9 ± 0.1 b	1.1 ± 0.2 a	nd	0.4 ± 0.1 de	1.0 ± 0.1 ab	0.7 ± 0.1 bc	nd	0.5 ± 0.1 d	0.000
17:0	0.8 ± 0.1 c	1.0 ± 0.1 b	2.0 ± 0.1 a	0.2 ± 0.1 f	0.4 ± 0.0 e	0.7 ± 0.1 cd	0.4 ± 0.0 e	0.6 ± 0.0 d	0.3 ± 0.1 ef	0.5 ± 0.0 de	0.5 ± 0.0 de	0.6 ± 0.1 d	0.000
17:1	1.1 ± 0.1 a	0.6 ± 0.0 b	0.5 ± 0.1 bc	0.5 ± 0.0 b	0.4 ± 0.0 c	0.5 ± 0.0 b	nd	0.2 ± 0.0 e	0.4 ± 0.0 c	0.3 ± 0.0 d	0.2 ± 0.0 e	0.2 ± 0.0 e	0.000
18:0	8.2 ± 0.5 ab	7.1 ± 0.4 c	7.6 ± 0.7 bc	5.3 ± 0.3 e	5.6 ± 0.2 de	6.3 ± 0.4 d	8.7 ± 0.6 a	4.3 ± 0.3 f	5.4 ± 0.4 e	7.6 ± 0.5 bc	5.7 ± 0.3 de	7.4 ± 0.6 bc	0.000
18:1n-9	19.9 ± 1.5 cd	20.3 ± 0.9 cd	14.2 ± 0.9 e	20.4 ± 1.1 cd	16.1 ± 0.9 e	19.1 ± 1.2 cd	21.4 ± 1.5 bc	21.0 ± 1.3 c	21.1 ± 1.5 c	18.4 ± 1.2 d	23.5 ± 1.7 b	25.9 ± 1.6 a	0.000
18:1n-7	1.2 ± 0.4 bc	0.9 ± 0.1 cd	0.6 ± 0.0 d	nd	0.7 ± 0.1 d	1.0 ± 0.2 c	1.6 ± 0.2 b	2.2 ± 0.3 a	1.3 ± 0.2 b	1.3 ± 0.1 b	1.2 ± 0.1 bc	1.5 ± 0.2 b	0.000
18:2n-6	1.2 ± 0.1 c	0.8 ± 0.0 e	2.7 ± 0.2 a	1.4 ± 0.1 b	0.4 ± 0.0 f	1.0 ± 0.0 d	0.4 ± 0.1 f	0.5 ± 0.0 f	1.2 ± 0.1 c	0.8 ± 0.0 e	1.4 ± 0.1 b	0.5 ± 0.1 f	0.000
18:3n-3	3.6 ± 0.3 a	0.9 ± 0.1 c	1.2 ± 0.1 b	1.0 ± 0.2 c	0.6 ± 0.0 d	0.5 ± 0.1 d	0.3 ± 0.0 e	0.6 ± 0.1 d	1.0 ± 0.1 c	1.0 ± 0.1 c	1.1 ± 0.1 bc	0.5 ± 0.0 d	0.000
18:4n-3	nd	nd	nd	nd	0.5 ± 0.0 a	nd	0.2 ± 0.0 d	0.3 ± 0.1 c	0.1 ± 0.0 e	0.2 ± 0.0 d	0.2 ± 0.0 d	0.4 ± 0.0 b	0.000
20:0	0.7 ± 0.0 b	0.2 ± 0.0 d	0.2 ± 0.0 d	0.7 ± 0.1 b	0.4 ± 0.1 cd	0.6 ± 0.1 bc	0.2 ± 0.0 d	0.2 ± 0.0 d	nd	1.1 ± 0.6 a	0.2 ± 0.0 d	0.3 ± 0.0 d	0.000
20:1	1.1 ± 0.1 c	1.3 ± 0.2 b	2.2 ± 0.2 a	1.1 ± 0.1 c	1.0 ± 0.1 c	0.6 ± 0.0 d	0.3 ± 0.0 e	0.6 ± 0.0 d	1.4 ± 0.1 b	0.1 ± 0.0 f	1.1 ± 0.1 c	0.3 ± 0.0 e	0.000
20:2n-6	0.4 ± 0.0 a	0.2 ± 0.0 c	0.3 ± 0.1 ab	0.2 ± 0.0 c	nd	0.2 ± 0.0 c	nd	0.3 ± 0.0 b	0.4 ± 0.1 a	0.3 ± 0.0 b	0.3 ± 0.01 ab	0.4 ± 0.1 a	0.000
20:3n-6	nd	nd	0.1 ± 0.0 c	nd	0.6 ± 0.0 a	0.3 ± 0.0 b	0.3 ± 0.0 b	nd	nd	nd	0.2 ± 0.0 b	0.2 ± 0.0 b	0.000
20:4n-6	2.8 ± 0.3 a	1.6 ± 0.1 cd	2.5 ± 0.3 b	1.6 ± 0.2 cd	0.2 ± 0.0 g	0.7 ± 0.2 f	0.5 ± 0.1 f	0.7 ± 0.1 f	1.8 ± 0.1 c	0.7 ± 0.0 f	1.5 ± 0.1 d	1.1 ± 0.1 e	0.000
20:5n-3	7.4 ± 0.5 b	6.8 ± 0.7 bc	8.7 ± 1.0 a	6.6 ± 0.4 bcd	6.1 ± 0.5 cd	7.2 ± 0.9 b	9.4 ± 0.7 a	5.5 ± 0.4 de	4.8 ± 0.4 e	8.6 ± 0.4 a	5.9 ± 0.4 cd	4.7 ± 0.5 e	0.000
22:0	0.4 ± 0.1 c	0.3 ± 0.0 d	0.2 ± 0.0 de	0.1 ± 0.0 e	nd	0.3 ± 0.0 d	1.3 ± 0.2 a	0.3 ± 0.0 d	1.4 ± 0.1 a	1.1 ± 0.1 b	nd	0.4 ± 0.0 c	0.000
22:1	0.3 ± 0.0 d	0.1 ± 0.0 e	0.1 ± 0.0 e	1.1 ± 0.1 a	nd	0.3 ± 0.0 d	0.7 ± 0.2 b	0.2 ± 0.0 de	0.5 ± 0.0 c	0.3 ± 0.1 d	0.2 ± 0.0 de	0.7 ± 0.01 b	0.000
22:4n-6	0.1 ± 0.0 d	0.3 ± 0.0 c	0.2 ± 0.0 cd	nd	0.2 ± 0.0 cd	0.2 ± 0.0 cd	0.3 ± 0.0 c	0.4 ± 0.0 b	0.3 ± 0.0 c	0.3 ± 0.0 c	0.2 ± 0.0 cd	0.5 ± 0.1 a	0.000
22:5n-6	0.3 ± 0.0 b	0.4 ± 0.1 a	nd	0.2 ± 0.0 bc	nd	nd	0.2 ± 0.0 bc	0.1 ± 0.0 c	0.4 ± 0.0 a	0.2 ± 0.0 bc	0.2 ± 0.0 bc	0.3 ± 0.0 b	0.000
22:5n-3	3.5 ± 0.3 b	3.4 ± 0.3 b	2.4 ± 0.1 c	3.9 ± 0.1 a	1.2 ± 0.1 e	1.7 ± 0.2 d	3.9 ± 0.5 a	1.2 ± 0.1 e	1.8 ± 0.1 d	0.6 ± 0.0 f	1.9 ± 0.1 d	4.3 ± 0.4 a	0.000
22:6n-3	11.8 ± 0.8 d	17.4 ± 1.2 b	22.9 ± 1.5 a	18.7 ± 0.8 b	6.6 ± 0.5 e	11.5 ± 0.8 d	15.2 ± 0.8 c	14.6 ± 1.3 c	14.2 ± 0.8 c	12.4 ± 0.8 d	17.7 ± 1.1 b	15.4 ± 0.8 c	0.000
other	4.8 ± 0.7	3.7 ± 0.4	6.0 ± 0.6	6.6 ± 1.0	8.8 ± 0.7	9.6 ± 0.9	7.3 ± 0.3	5.0 ± 0.5	4.4 ± 0.3	6.6 ± 0.9	4.9 ± 0.3	5.1 ± 0.4	
total SFA	35.3 ± 0.9 bc	35.0 ± 1.3 bc	31.2 ± 1.3 de	30.1 ± 1.9 e	37.4 ± 1.7 b	34.0 ± 2.0 cd	34.5 ± 1.9 bc	35.4 ± 1.4 bc	36.2 ± 2.2 bc	40.6 ± 1.5 a	31.4 ± 1.2 de	33.4 ± 1.6 cd	0.000
total MUFA	28.8 ± 1.3 c	29.7 ± 1.1 c	21.7 ± 0.7 d	29.6 ± 1.4 c	37.6 ± 1.4 a	33.2 ± 1.6 b	27.6 ± 1.4 c	35.5 ± 2.0 ab	33.5 ± 1.7 b	27.9 ± 1.4 c	33.3 ± 2.4 b	33.4 ± 0.8 b	0.000
total PUFA	31.2 ± 0.9 bc	31.6 ± 1.4 bc	41.1 ± 2.3 a	33.8 ± 2.0 b	16.3 ± 0.9 g	23.2 ± 1.6 f	30.7 ± 2.2 cd	24.1 ± 1.2 f	25.9 ± 1.2 ef	24.9 ± 1.5 f	30.4 ± 1.8 cd	28.1 ± 1.3 de	0.000
total n-3	26.4 ± 0.8 cd	28.4 ± 0.9 bc	35.2 ± 1.4 a	30.3 ± 1.8 b	14.9 ± 0.8 f	20.8 ± 1.2 e	29.0 ± 1.7 b	22.2 ± 1.1 e	21.8 ± 0.9 e	22.8 ± 1.0 e	26.6 ± 1.2 cd	25.3 ± 1.4 d	0.000
total n-6	4.8 ± 0.5 b	3.3 ± 0.1 e	5.9 ± 0.2 a	3.5 ± 0.2 de	1.4 ± 0.1 i	2.3 ± 0.3 g	1.7 ± 0.2 hi	1.9 ± 0.1 gh	4.1 ± 0.4 c	2.1 ± 0.1 gh	3.8 ± 0.4 cd	2.8 ± 0.1 f	0.000
n-3/n-6	5.5 ± 0.2 f	8.6 ± 0.3 d	6.0 ± 0.4 f	8.7 ± 0.4 d	10.6 ± 0.3 bc	9.0 ± 0.5 cd	17.1 ± 0.7 a	11.7 ± 0.5 b	5.3 ± 0.1 f	10.9 ± 0.4 bc	7.0 ± 0.2 e	9.0 ± 0.5 cd	0.000

[a] Results are presented as mean ± SD ($n = 5$). Values within the same row not sharing a common superscript letter are significantly different ($P < 0.05$); nd = not detected, SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids.

with previous studies on fatty acid composition of other marine fish species.[18,25−27] EPA and DHA represented the most abundant n-3 PUFA, together accounting for 12.7% of total fatty acids in white Chinese croaker to 31.6% in melon seed. Similar results were also found in fish from other regions.[3,9,18,23] Osman et al.[26] attributed it to the staple diets (plankton) of marine fish in the seawater which contained large amounts of n-3 PUFA, especially EPA and DHA. The levels of DHA, which varied from 6.6% of total fatty acids in white Chinese croaker to 22.9% in melon seed, were always higher than those of EPA, which varied from 4.7% of total fatty acids in Chinese silver promfret to 9.4% in bluefin leather jacket. This is in agreement with the marine fish from the Southeast Brazilian coast[3] and Turkey.[2]

In the present study, the fatty acid composition in the edible meat of the studied marine fish was strongly affected by their trophic levels and food habits (Tables 1 and 2). Omnivorous fish (melon seed and chub mackerel) with trophic levels below 3.30 had higher total PUFA, n-3 PUFA, and EPA + DHA, but lower total SFA compositions than the carnivorous fish (trophic level >3.47). This is due to the fact that the present omnivorous marine fish feed on phytoplankton which contained higher levels of total PUFA, n-3 PUFA, EPA and DHA than the aquatic animals (the main food sources of carnivorous fish)[28−30] (Table 1). Among carnivorous fish, the species with high trophic levels (>3.60) demonstrated higher total PUFA, n-3 PUFA, and EPA + DHA, but lower total SFA levels than those with low trophic levels (<3.60). This can be explained by the fact that high trophic level carnivorous fish including white herring, largehead hairtail, bluefin leather jacket, small yellow croaker, pike eel, bombay duck, Spanish mackerel, and Chinese silver pomfret like eating small fish and crustaceans, while low trophic level carnivorous fish including white Chinese croaker and spotted maigre mainly prey on zooplankton and benthic invertebrate as primary food (Table 1), which usually had lower total PUFA and n-3 PUFA than small fish and crustaceans.[28]

Fatty Acid Composition of Freshwater Fish. The fatty acid composition in the edible meat of freshwater fish species is listed in Table 3. A total of 25 fatty acids, including 7 individual SFA, 8 individual MUFA, and 10 individual PUFA, were identified and determined. All fatty acids varied significantly among fish species ($P < 0.05$). Total PUFA and MUFA ranged from 17.7% of total fatty acids in cultured common carp to 48.9% in cultured silver carp and from 18.9% in cultured silver carp to 42.0% in cultured common carp, respectively, whereas total SFA ranged from 23.1% in cultured grass carp and black carp to 35.6% in cultured silver carp. These results are similar to the fatty acid composition of Malaysian freshwater fish.[16]

In the case of SFA, 16:0 represented the most abundant fatty acid in all studied freshwater fish species, accounting for 14.2% of total fatty acids in cultured bighead carp to 21.9% in cultured Chinese perch. This fatty acid has been reported in many studies as the major SFA in freshwater fish.[2,10,16] Just like the marine fish in the present study, the most abundant individual MUFA in all freshwater fish were 16:1n-7 and 18:1n-9. This is in agreement with the numerous studies on the fatty acid profile of freshwater fish originating from other sites.[2,10,16] As for PUFA, the levels of total n-3 ones in more than half of the studied freshwater fish species were lower than those of n-6 ones. This may be one of the biggest differences between freshwater and marine fish.[2] However, two freshwater fish, including bighead carp and silver carp, displayed much higher levels of total n-3 PUFA than n-6 PUFA. They even had higher levels of EPA and DHA than those of some studied marine fish. This may be due to the fact that bighead carp and silver carp are typical filter-feeder fish. They mainly feed on the plankton, which contain a high proportion of PUFA, especially long-chain n-3 PUFA (EPA and DHA), in the freshwater through gill raker.[31] Linolenic acid (18:3n-3) and DHA were the major n-3 PUFA in most studied freshwater fish, while linoleic acid (18:2n-6) and arachidonic acid (20:4n-6) were the predominant n-6 PUFA in all freshwater fish. Such results have also been shown in many previous studies of freshwater fish.[2,10,16] In our study, the cultured freshwater fish, including crucian carp, snakehead and bighead carp, demonstrated higher percentages of total PUFA, total n-3 PUFA, and EPA + DHA than the wild freshwater fish. This can be explained by the fact that many cultured freshwater fish in China have a diet containing a large proportion of marine fish powder.[32] Song et al.[33] reported that the total PUFA, n-3 PUFA, EPA, and DHA compositions of marine fish powder used in Chinese aquaculture ranged from 35.2 to 46.7, 30.8 to 41.8, 8.5 to 15.1, and 15.7 to 25.9% of total fatty acids, respectively. Such values were much higher than those of aquatic plants and animals which were the main natural food sources of wild freshwater fish.[11,28,39]

In the present study, a strong relationship between food habits, trophic levels, and fatty acid compositions was also observed in the edible meat of freshwater fish (Tables 1 and 3). Omnivorous fish (bighead carp and silver carp) with low trophic levels (2.00−2.33) which mainly feed on plankton had the highest total PUFA, n-3 PUFA, and EPA + DHA, but lowest n-6 PUFA compositions, while other omnivorous and herbivorous fish (crucian carp, common carp, and grass carp) which like eating plant materials had the lowest total n-3 PUFA and EPA + DHA, but highest n-6 PUFA compositions. The fatty acid compositions in the edible meat of carnivorous fish (Chinese perch, snakehead, swamp eel, and Oriental weatherfish) with high trophic levels (3.24−4.50) which mainly feed on aquatic animals were in between. Compared with plant materials like aquatic plants, submerged grasses and vegetables, plankton had much higher total n-3 PUFA but lower n-6 PUFA compositions.[31]

Fatty Acid Composition of Shrimps. Table 4 shows the fatty acid composition in the edible meat of 7 different shrimp species. Though all the shrimps had very low lipid content, they presented a high nutritional value in terms of their fatty acids. The PUFA, ranging from 32.8% of total fatty acids in Oriental river shrimp to 47.5% in fleshy prawn, predominated over the SFA (from 25.5% in ridgetail white prawn to 38.4% in Oriental river shrimp) and MUFA (from 19.4% in fleshy prawn to 29.3% in ridgetail white prawn) levels. This composition pattern agrees with the results found in other shrimps[20,34] and shellfish.[35,36] However, some studies concluded the SFA as the most abundant fatty acids in some shrimps.[37,38] These discrepancies can be partially attributed to the different environmental conditions and diets which have been reported to have a dominant influence on the fatty acid composition of shrimps.[34,38]

Just like the marine and freshwater fish, the fatty acid compositions of shrimps were species specific. The predominant individual SFA was 16:0. It ranged from 14.4% of total fatty acids in mantis shrimp to 26.4% in Oriental river shrimp. 18:1n-9 represented the most abundant individual MUFA in all studied shrimps, accounting for 10.7% of the total fatty acids in fleshy prawn to 17.3% in Oriental river shrimp. 16:0 and 18:1n-9 have been considered as the major individual SFA and MUFA, respectively, in shrimps in the previous literature.[20,37] Among PUFA, the levels of the total n-3 fraction varied from 17.2% of total fatty acids in Oriental river shrimp to 32.2% in mantis shrimp, while

Table 3. Fatty Acid Composition (% of Total Fatty Acids) in the Edible Meat of Freshwater Fish[a]

	crucian carp		Chinese perch		bighead carp		snakehead							Oriental	
fatty acid	wild	cultural	wild	cultural	wild	cultural	wild	cultural	grass carp	common carp	black carp	silver carp	swamp eel	weatherfish	P-value
14:0	1.2 ± 0.0 fg	1.2 ± 0.1 fg	2.9 ± 0.3 c	3.6 ± 0.2 b	1.8 ± 0.3 de	3.0 ± 0.3 c	2.1 ± 0.1 d	2.6 ± 0.2 c	0.9 ± 0.1 gh	4.2 ± 0.4 a	1.7 ± 0.1 de	1.4 ± 0.1 ef	1.9 ± 0.1 d	0.7 ± 0.1 h	0.000
15:0	0.3 ± 0.1 gh	0.5 ± 0.1 efg	1.1 ± 0.1 c	1.4 ± 0.2 bc	0.6 ± 0.2 def	0.7 ± 0.2 de	1.5 ± 0.0 b	0.4 ± 0.1 fgh	nd	3.8 ± 0.3 a	0.2 ± 0.0 h	0.7 ± 0.1 de	1.5 ± 0.1 b	0.8 ± 0.0 d	0.000
15:1	0.7 ± 0.1 bc	0.3 ± 0.1 d	0.5 ± 0.2 c	1.5 ± 0.2 a	0.2 ± 0.0 d	0.8 ± 0.1 b	0.3 ± 0.0 d	0.2 ± 0.0 de	nd	0.6 ± 0.1 bc	0.1 ± 0.0 e	nd	nd	0.2 ± 0.0 d	0.000
16:0	18.1 ± 0.9 cde	16.9 ± 0.5 de	19.9 ± 0.5 bc	21.9 ± 0.4 a	18.8 ± 0.7 bcd	14.2 ± 1.0 f	21.8 ± 0.7 a	17.9 ± 1.8 cde	17.2 ± 0.8 de	19.4 ± 1.2 bc	16.6 ± 1.2 e	20.3 ± 1.8 ab	18.2 ± 0.8 cde	17.6 ± 0.8 cde	0.000
16:1n-7	6.2 ± 0.2 de	4.7 ± 0.1 g	5.1 ± 0.8 fg	8.5 ± 0.4 b	5.2 ± 0.8 efg	6.7 ± 0.8 cd	9.2 ± 0.2 b	7.3 ± 0.8 c	3.5 ± 0.2 h	11.9 ± 0.7 a	6.2 ± 0.5 de	4.7 ± 0.4 g	5.9 ± 0.5 def	5.3 ± 0.4 efg	0.000
16:1n-9	0.4 ± 0.1 ef	0.4 ± 0.1 ef	0.5 ± 0.0 de	1.1 ± 0.1 b	nd	nd	0.3 ± 0.0 f	0.3 ± 0.1 f	nd	1.1 ± 0.1 b	nd	0.9 ± 0.1 c	2.3 ± 0.2 a	0.6 ± 0.0 d	0.000
17:0	0.5 ± 0.3 f	0.4 ± 0.2 f	1.2 ± 0.2 bcd	1.3 ± 0.4 bc	1.1 ± 0.3 bcd	1.5 ± 0.1 b	1.5 ± 0.0 b	0.9 ± 0.1 cde	0.8 ± 0.1 de	4.5 ± 0.4 a	0.7 ± 0.1 ef	0.6 ± 0.1 ef	0.6 ± 0.1 ef	0.6 ± 0.1 ef	0.000
17:1	0.6 ± 0.1 ef	0.4 ± 0.0 fg	1.0 ± 0.2 bcd	1.0 ± 0.1 bc	0.9 ± 0.3 cd	1.2 ± 0.2 b	2.3 ± 0.1 a	0.7 ± 0.1 de	1.1 ± 0.1 bc	0.9 ± 0.2 cd	nd	nd	0.2 ± 0.0 g	0.8 ± 0.1 de	0.000
18:0	4.6 ± 0.3 cd	4.1 ± 0.2 de	5.0 ± 0.5 bc	3.6 ± 0.4 e	5.6 ± 0.3 b	6.5 ± 0.3 a	4.0 ± 0.0 de	6.6 ± 0.9 a	4.2 ± 0.4 cde	5.7 ± 0.7 b	3.9 ± 0.2 de	4.2 ± 0.5 cde	5.5 ± 0.4 b	6.5 ± 0.4 a	0.000
18:1n-9	27.4 ± 1.3 ab	26.6 ± 1.7 ab	25.5 ± 1.7 abc	23.1 ± 1.7 cd	21.4 ± 2.2 d	7.8 ± 1.2 g	23.2 ± 0.3 cd	20.9 ± 1.5 d	28.5 ± 1.3 a	24.7 ± 1.7 bc	28.4 ± 2.4 a	10.8 ± 1.1 f	20.5 ± 2.5 d	17.5 ± 1.2 e	0.000
18:1n-7	3.1 ± 0.2 c	nd	1.3 ± 0.0 f	nd	nd	3.7 ± 0.6 b	nd	nd	1.9 ± 0.2 e	2.3 ± 0.1 d	nd	2.4 ± 0.2 d	4.2 ± 0.3 a	1.3 ± 0.1 f	0.000
18:2n-6	11.4 ± 0.2 d	17.0 ± 0.2 b	7.8 ± 0.8 e	7.6 ± 0.1 e	5.7 ± 0.4 fg	4.8 ± 0.6 g	5.9 ± 0.3 fg	7.6 ± 0.9 e	15.9 ± 0.5 b	6.3 ± 0.5 f	18.4 ± 1.4 a	2.4 ± 0.2 h	13.7 ± 1.1 c	6.3 ± 0.4 f	0.000
18:3n-3	4.0 ± 0.2 efg	2.6 ± 0.2 hi	3.7 ± 0.4 fg	5.5 ± 0.4 c	5.4 ± 0.7 c	5.2 ± 0.4 cd	4.4 ± 0.1 def	4.6 ± 0.7 de	8.0 ± 0.5 b	3.3 ± 0.1 gh	9.3 ± 0.8 a	4.4 ± 0.4 def	3.7 ± 0.3 fg	2.3 ± 0.2 i	0.000
20:0	0.1 ± 0.0 c	0.1 ± 0.0 c	0.2 ± 0.0 b	0.2 ± 0.0 b	0.1 ± 0.0 c	0.3 ± 0.1 b	0.1 ± 0.0 c	0.2 ± 0.0 b	nd	0.9 ± 0.1 a	nd	0.2 ± 0.0 b	0.2 ± 0.0 b	nd	0.000
20:1	1.1 ± 0.1 de	2.8 ± 0.3 a	0.7 ± 0.3 f	0.7 ± 0.1 f	1.9 ± 0.1 c	3.0 ± 0.2 a	1.3 ± 0.1 d	1.9 ± 0.3 c	0.9 ± 0.1 ef	1.7 ± 0.2 c	nd	nd	1.3 ± 0.1 d	2.3 ± 0.1 b	0.000
20:2n-6	1.7 ± 0.1 a	1.3 ± 0.1 b	0.5 ± 0.1 de	0.4 ± 0.1 e	0.7 ± 0.1 cd	0.5 ± 0.1 de	0.5 ± 0.1 de	0.5 ± 0.1 de	0.7 ± 0.1 cd	0.8 ± 0.0 c	1.5 ± 0.1 a	1.2 ± 0.1 b	0.8 ± 0.1 c	0.7 ± 0.0 cd	0.000
20:3n-6	1.3 ± 0.2 cd	2.0 ± 0.1 b	2.9 ± 0.1 a	1.0 ± 0.3 cde	1.1 ± 0.0 cd	1.2 ± 0.1 cd	0.8 ± 0.0 e	1.4 ± 0.2 c	1.1 ± 0.1 cd	0.8 ± 0.2 e	1.2 ± 0.2 cd	0.9 ± 0.1 de	1.4 ± 0.1 c	0.4 ± 0.0 f	0.000
20:4n-6	3.6 ± 0.5 c	4.0 ± 0.1 bc	4.8 ± 1.1 b	3.6 ± 0.2 c	4.1 ± 0.3 bc	3.6 ± 0.3 c	3.6 ± 0.1 c	4.4 ± 0.6 bc	2.2 ± 0.4 d	1.8 ± 0.1 d	2.0 ± 0.1 d	4.9 ± 0.3 b	3.7 ± 0.4 c	8.5 ± 0.6 a	0.000
20:5n-3	1.8 ± 0.2 ef	1.5 ± 0.1 ef	1.7 ± 0.2 ef	2.2 ± 0.2 de	7.6 ± 0.6 b	14.1 ± 0.5 a	1.7 ± 0.1 ef	2.6 ± 0.3 d	1.2 ± 0.1 fgh	0.8 ± 0.0 h	0.9 ± 0.1 gh	13.8 ± 1.0 a	1.9 ± 0.2 e	4.3 ± 0.3 c	0.000
22:0	0.2 ± 0.0 cd	0.2 ± 0.0 cd	0.4 ± 0.1 b	0.2 ± 0.0 cd	0.3 ± 0.0 bc	0.4 ± 0.1 b	0.6 ± 0.1 a	0.3 ± 0.0 bc	0.3 ± 0.0 bc	nd	0.1 ± 0.0 d	nd	0.2 ± 0.0 cd	0.2 ± 0.0 cd	0.000
22:1	0.2 ± 0.0 e	0.2 ± 0.0 e	0.3 ± 0.0 de	0.5 ± 0.1 c	0.3 ± 0.0 de	0.5 ± 0.1 c	0.4 ± 0.0 cd	0.3 ± 0.0 de	1.0 ± 0.1 a	0.7 ± 0.1 b	0.4 ± 0.0 cd	nd	0.3 ± 0.0 de	0.6 ± 0.1 bc	0.000
22:4n-6	0.5 ± 0.1 e	0.4 ± 0.1 ef	0.8 ± 0.1 d	0.5 ± 0.1 e	0.2 ± 0.0 g	nd	0.5 ± 0.1 e	0.7 ± 0.1 d	0.4 ± 0.1 ef	1.4 ± 0.2 c	0.3 ± 0.0 fg	2.0 ± 0.1 b	0.5 ± 0.0 e	3.5 ± 0.2 a	0.000
22:5n-6	1.3 ± 0.3 d	1.4 ± 0.1 cd	1.9 ± 0.1 b	1.2 ± 0.3 de	0.9 ± 0.2 f	2.4 ± 0.3 a	0.9 ± 0.1 f	1.2 ± 0.4 de	0.4 ± 0.1 g	0.2 ± 0.0 h	0.5 ± 0.1 g	1.3 ± 0.2 d	0.4 ± 0.1 g	1.7 ± 0.1 bc	0.000
22:5n-3	1.1 ± 0.1 fg	0.8 ± 0.1 gh	1.5 ± 0.1 ef	1.5 ± 0.2 de	1.9 ± 0.3 d	3.6 ± 0.2 ab	2.7 ± 0.2 c	3.9 ± 0.5 a	1.4 ± 0.2 ef	0.6 ± 0.0 h	0.9 ± 0.1 gh	2.5 ± 0.3 c	0.9 ± 0.1 gh	3.4 ± 0.2 b	0.000
22:6n-3	5.0 ± 0.4 f	6.7 ± 0.3 e	5.5 ± 0.2 ef	5.1 ± 0.3 f	10.1 ± 0.9 c	12.5 ± 1.7 b	6.7 ± 0.5 e	8.5 ± 0.8 d	3.3 ± 0.1 g	1.8 ± 0.2 h	0.4 ± 0.0 i	15.5 ± 2.1 a	5.3 ± 0.5 ef	8.2 ± 0.5 d	0.000
other	3.7 ± 0.3	3.9 ± 0.6	3.5 ± 0.6	4.9 ± 0.7	4.1 ± 0.1	4.0 ± 0.4	5.7 ± 0.8	4.1 ± 0.5	5.0 ± 0.6	4.7 ± 0.4	5.1 ± 0.8	4.9 ± 0.7	4.8 ± 0.4	5.6 ± 0.7	
total SFA	25.1 ± 0.7 gh	23.3 ± 1.0 h	30.6 ± 1.5 bc	32.1 ± 1.3 b	28.3 ± 0.9 cde	25.5 ± 0.8 fgh	29.7 ± 1.7 cd	29.0 ± 0.5 cd	23.1 ± 1.8 h	35.6 ± 2.4 a	23.1 ± 1.5 h	27.3 ± 1.2 defg	27.9 ± 1.4 def	26.3 ± 1.5 efg	0.000
total MUFA	39.6 ± 2.3 ab	35.4 ± 1.9 c	34.8 ± 2.5 cd	34.3 ± 1.4 cd	30.0 ± 2.0 e	22.6 ± 1.4 f	36.9 ± 2.1 bc	31.5 ± 1.1 de	37.0 ± 1.7 bc	42.0 ± 2.5 a	36.4 ± 2.7 bc	18.9 ± 0.9 g	34.7 ± 1.7 cd	28.5 ± 1.1 e	0.000
total PUFA	31.5 ± 1.7 def	37.7 ± 2.4 bc	31.0 ± 1.4 efg	28.6 ± 0.7 fg	37.7 ± 2.2 bc	47.9 ± 3.5 a	27.7 ± 1.9 g	35.4 ± 2.1 cd	34.7 ± 1.6 cde	17.7 ± 0.8 h	35.3 ± 1.9 cd	48.9 ± 3.1 a	32.4 ± 2.1 de	39.4 ± 2.1 b	0.000
total n-3	11.8 ± 0.5 f	11.6 ± 0.5 f	12.4 ± 0.7 ef	14.3 ± 0.6 de	24.9 ± 1.8 b	35.4 ± 2.8 a	15.5 ± 1.2 d	19.5 ± 1.2 c	13.9 ± 0.4 def	6.4 ± 0.3 g	11.5 ± 0.4 f	36.2 ± 2.3 a	11.9 ± 0.8 f	18.2 ± 1.2 c	0.000
total n-6	19.7 ± 1.1 cd	26.1 ± 1.3 a	18.7 ± 1.0 d	14.3 ± 0.8 ef	12.7 ± 0.6 fg	12.5 ± 0.5 fg	12.2 ± 0.9 g	15.8 ± 0.7 e	20.8 ± 1.3 c	11.3 ± 0.7 g	23.8 ± 1.7 b	12.7 ± 0.6 fg	20.5 ± 1.3 cd	21.2 ± 0.8 c	0.000
n-3/n-6	0.6 ± 0.0 fg	0.4 ± 0.0 h	0.7 ± 0.1 efg	1.0 ± 0.0 d	2.0 ± 0.1 b	2.9 ± 0.2 a	1.3 ± 0.1 c	1.2 ± 0.1 c	0.7 ± 0.0 fg	0.6 ± 0.0 fg	0.5 ± 0.0 gh	2.9 ± 0.1 a	0.6 ± 0.0 fg	0.9 ± 0.1 de	0.000

[a] Results are presented as mean ± SD ($n = 5$). Values within the same row not sharing a common superscript letter are significantly different ($P < 0.05$). nd = not detected, SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids.

Table 4. Fatty Acid Composition (% of Total Fatty Acids) in the Edible Meat of Shrimps[a]

fatty acid	mantis shrimp	ridgetail white prawn	fleshy prawn	giant freshwater prawn	whiteleg shrimp	Oriental river shrimp	Cipango prawn	*P*-value
12:0	4.4 ± 0.2 a	nd	nd	nd	0.4 ± 0.0 b	0.1 ± 0.0 c	0.2 ± 0.0 c	0.000
14:0	0.8 ± 0.1 cd	0.6 ± 0.1 de	0.4 ± 0.0 e	1.0 ± 0.1 c	0.8 ± 0.1 cd	3.1 ± 0.3 b	3.7 ± 0.1 a	0.000
15:0	0.1 ± 0.0 d	0.3 ± 0.1 b	0.3 ± 0.0 b	0.2 ± 0.0 c	0.3 ± 0.0 b	0.6 ± 0.0 a	0.6 ± 0.0 a	0.000
15:1	nd	1.4 ± 0.1 b	2.4 ± 0.2 a	2.4 ± 0.3 a	1.2 ± 0.1 b	nd	nd	0.000
16:0	14.4 ± 0.7 e	15.9 ± 0.6 de	17.5 ± 0.9 cd	18.4 ± 1.0 c	20.0 ± 1.0 b	26.4 ± 1.3 a	16.3 ± 1.1 de	0.000
16:1n-7	9.2 ± 0.5 a	4.9 ± 0.3 c	1.2 ± 0.1 f	1.7 ± 0.2 e	2.3 ± 0.1 d	4.8 ± 0.2 c	8.4 ± 0.4 b	0.000
16:1n-9	nd	0.4 ± 0.1 c	nd	nd	nd	0.6 ± 0.0 b	0.9 ± 0.1 a	0.000
17:0	1.1 ± 0.1 c	1.7 ± 0.3 a	1.2 ± 0.1 c	1.2 ± 0.1 c	1.4 ± 0.1 b	1.0 ± 0.1 c	1.1 ± 0.1 c	0.000
17:1	0.2 ± 0.0 e	2.9 ± 0.2 b	2.2 ± 0.2 c	4.6 ± 0.4 a	0.8 ± 0.1 d	0.8 ± 0.1 d	1.1 ± 0.1 d	0.000
18:0	4.1 ± 0.1 g	6.1 ± 0.4 e	8.3 ± 0.5 b	7.9 ± 0.4 bc	10.3 ± 0.8 a	6.7 ± 0.4 de	7.4 ± 0.4 cd	0.000
18:1n-9	12.5 ± 1.0 c	12.1 ± 0.4 c	10.7 ± 0.5 d	13.1 ± 0.9 c	15.8 ± 1.1 b	17.3 ± 0.9 a	13.5 ± 0.5 c	0.000
18:1n-7	2.2 ± 0.2 c	6.5 ± 0.8 a	2.5 ± 0.2 c	3.4 ± 0.3 b	1.4 ± 0.1 d	1.5 ± 0.1 d	1.1 ± 0.1 e	0.000
18:2n-6	1.7 ± 0.1 e	3.7 ± 0.4 d	11.4 ± 0.8 b	16.4 ± 1.1 a	8.9 ± 0.4 c	8.7 ± 0.5 c	1.3 ± 0.1 e	0.000
18:3n-3	2.2 ± 0.3 b	2.7 ± 0.3 a	1.2 ± 0.1 d	1.4 ± 0.1 cd	1.6 ± 0.1 c	2.0 ± 0.1 b	1.1 ± 0.1 d	0.000
18:3n-6	0.3 ± 0.0 c	nd	nd	0.1 ± 0.0 d	nd	0.5 ± 0.0 a	0.4 ± 0.0 b	0.000
18:4n-3	0.8 ± 0.0 a	nd	nd	0.3 ± 0.1 b	0.7 ± 0.0 a	nd	nd	0.000
20:0	0.2 ± 0.1 c	0.6 ± 0.1 a	nd	nd	0.4 ± 0.0 b	nd	nd	0.000
20:1	0.7 ± 0.1 bc	1.0 ± 0.2 a	0.4 ± 0.0 d	0.4 ± 0.1 d	0.8 ± 0.1 ab	0.5 ± 0.1 cd	0.4 ± 0.0 d	0.000
20:2n-6	nd	nd	1.3 ± 0.1 a	0.7 ± 0.1 b	0.7 ± 0.1 b	0.5 ± 0.0 c	0.3 ± 0.0 d	0.000
20:3n-6	0.2 ± 0.0 c	nd	nd	nd	0.5 ± 0.0 b	1.8 ± 0.1 a	0.2 ± 0.0 c	0.000
20:3n-3	nd	0.2 ± 0.0 b	0.1 ± 0.0 c	0.2 ± 0.0 b	nd	0.3 ± 0.0 a	nd	0.000
20:4n-6	5.0 ± 0.4 b	3.0 ± 0.1 d	2.3 ± 0.2 e	5.0 ± 0.5 b	4.2 ± 0.3 c	3.8 ± 0.2 c	6.6 ± 0.4 a	0.000
20:5n-3	13.2 ± 1.2 c	17.2 ± 0.7 a	15.2 ± 1.1 b	11.6 ± 0.9 d	12.3 ± 0.7 cd	8.1 ± 0.6 e	13.8 ± 0.9 bc	0.000
22:0	0.6 ± 0.1 a	0.4 ± 0.1 b	0.3 ± 0.0 c	0.2 ± 0.0 d	0.3 ± 0.0 c	0.4 ± 0.1 b	0.4 ± 0.0 b	0.000
22:1	1.2 ± 0.1	nd	nd	nd	nd	nd	nd	
22:4n-6	0.9 ± 0.2	nd	nd	nd	nd	nd	nd	
22:5n-6	1.1 ± 0.1 a	0.8 ± 0.1 b	1.1 ± 0.2 a	0.8 ± 0.1 b	0.7 ± 0.1 b	0.4 ± 0.0 c	0.5 ± 0.0 c	0.000
22:6n-3	16.0 ± 0.9 a	11.4 ± 0.6 b	14.9 ± 0.8 a	4.9 ± 0.2 e	9.1 ± 0.4 c	6.8 ± 0.4 d	15.2 ± 1.0 a	0.000
other	7.1 ± 1.5	6.2 ± 1.3	5.1 ± 0.9	4.2 ± 0.8	4.9 ± 0.4	3.3 ± 0.4	5.4 ± 0.8	
total SFA	25.6 ± 1.0 d	25.5 ± 1.2 d	28.0 ± 1.7 cd	28.9 ± 1.4 c	34.0 ± 1.2 b	38.4 ± 2.1 a	29.7 ± 1.5 bc	0.000
total MUFA	25.9 ± 1.3 b	29.3 ± 1.8 a	19.4 ± 0.6 d	25.5 ± 0.9 b	22.3 ± 1.2 c	25.5 ± 0.9 b	25.4 ± 1.3 b	0.000
total PUFA	41.3 ± 1.3 b	39.1 ± 1.3 b	47.5 ± 2.0 a	41.4 ± 1.8 b	38.8 ± 1.9 b	32.8 ± 1.6 c	39.5 ± 2.3 b	0.000
total n-3	32.2 ± 1.8 a	31.5 ± 0.9 a	31.4 ± 1.4 a	18.3 ± 0.6 c	23.7 ± 1.0 b	17.2 ± 0.8 c	30.1 ± 1.3 a	0.000
total n-6	9.1 ± 0.6 c	7.5 ± 0.4 d	16.0 ± 0.7 b	23.1 ± 1.3 a	15.1 ± 0.7 b	15.7 ± 0.7 b	9.4 ± 0.4 c	0.000
n-3/n-6	3.5 ± 0.2 ab	4.2 ± 0.2 a	2.0 ± 0.1 c	0.8 ± 0.1 e	1.6 ± 0.1 c	1.1 ± 0.0 d	3.2 ± 0.3 b	0.000

[a] Results are presented as mean ± SD ($n = 5$). Values within the same row not sharing a common superscript letter are significantly different ($P < 0.05$); nd = not detected, SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids.

those of the total n-6 fraction varied from 7.5% in ridgetail white prawn to 23.1% in giant freshwater prawn. Ridgetail white prawn presented the highest level of n-3/n-6 ratio (4.20), while giant freshwater prawn had the lowest level (0.79). These variations among species can be partially attributed to the different dietary sources, which were reported to have strong effects on the growth and fatty acid compositions of shrimps.[34,38] 20:4n-6 was the predominant individual n-6 PUFA, while EPA and DHA were the major n-3 PUFA in all shrimps. Similar results have been demonstrated in other shrimps.[20,34] Compared with the freshwater shrimps including giant freshwater prawn and Oriental river shrimp, the marine shrimps had much higher total n-3 PUFA, EPA + DHA compositions and n-3/n-6 ratios, but lower total n-6 PUFA compositions. This is mainly due to the different lipid sources in freshwater and marine food chain. It has been reported that the lipid sources in freshwater food chain had higher total n-3 PUFA, EPA, and DHA, but lower total n-6 PUFA compositions than those in marine food chain.[29,30,39]

Comparison of Fatty Acid Composition between Marine Fish, Freshwater Fish, and Shrimps. Multivariate analyses (NMDS ordination and hierarchical cluster analysis) using the fatty acid composition divided all studied fish and shrimps into six distinct groups (Figures 1A and 2). Most of the freshwater fish, including wild crucian carp (FF1), Chinese perch (FF3), snakehead (FF7), and cultured crucian carp (FF2), Chinese perch (FF4), grass carp (FF9), black carp (FF11), and swamp eel (FF13) clustered together (group 2), as did all marine fish except melon seed and white Chinese croaker (group 6). Four shrimps, including mantis shrimp (S1), ridgetail white prawn (S2), fleshy prawn (S3), and Cipango prawn (S7), grouped together with cultured bighead carp (FF6), silver carp (FF12), and melon seed (MF3) (group 4). Common carp (FF10) and white Chinese croaker (MF5) was classified as group 1 and group 5, respectively. The other three shrimps together with the remaining freshwater fish belonged to one group (group 3).

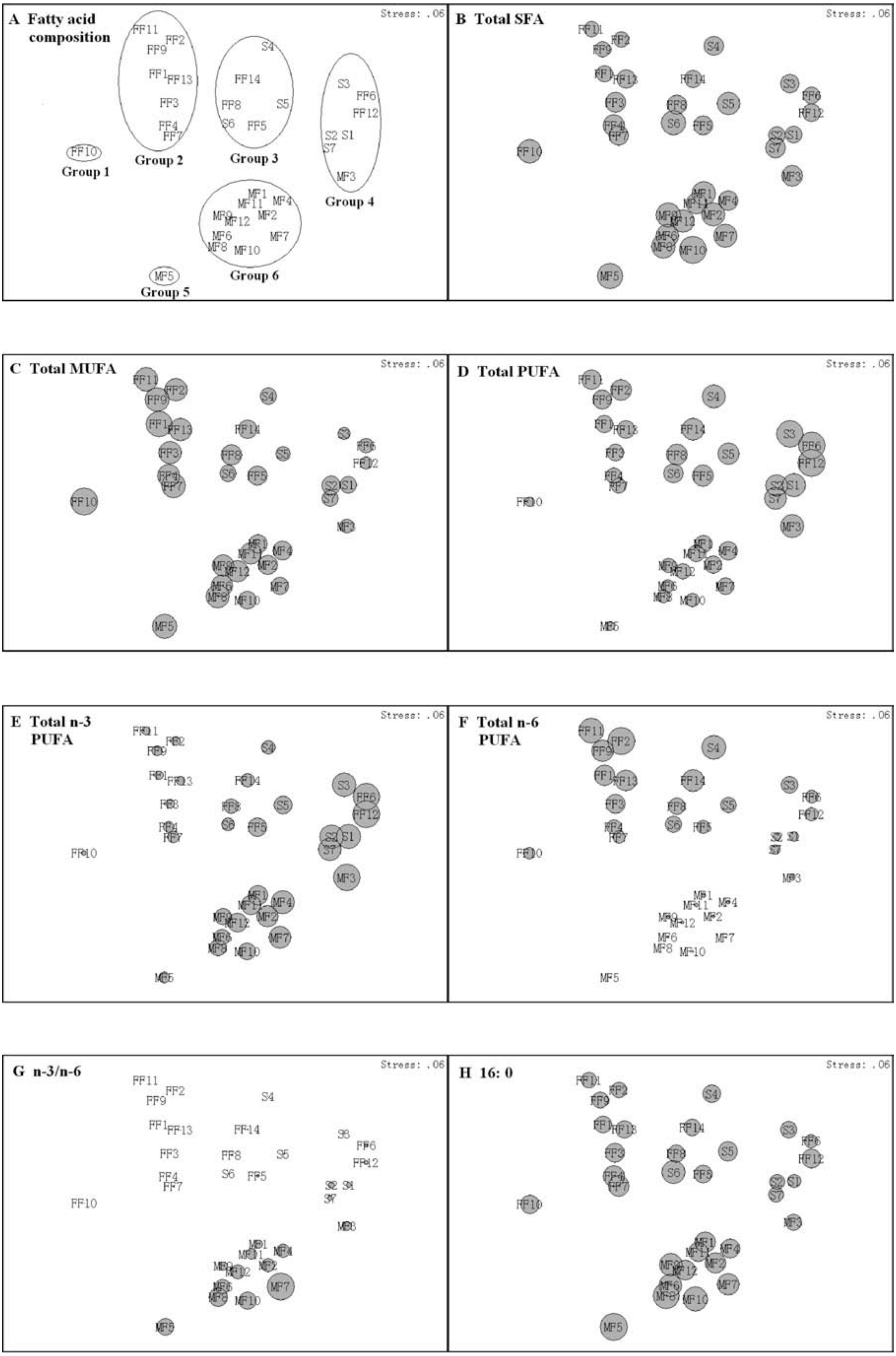

Figure 1. Continued

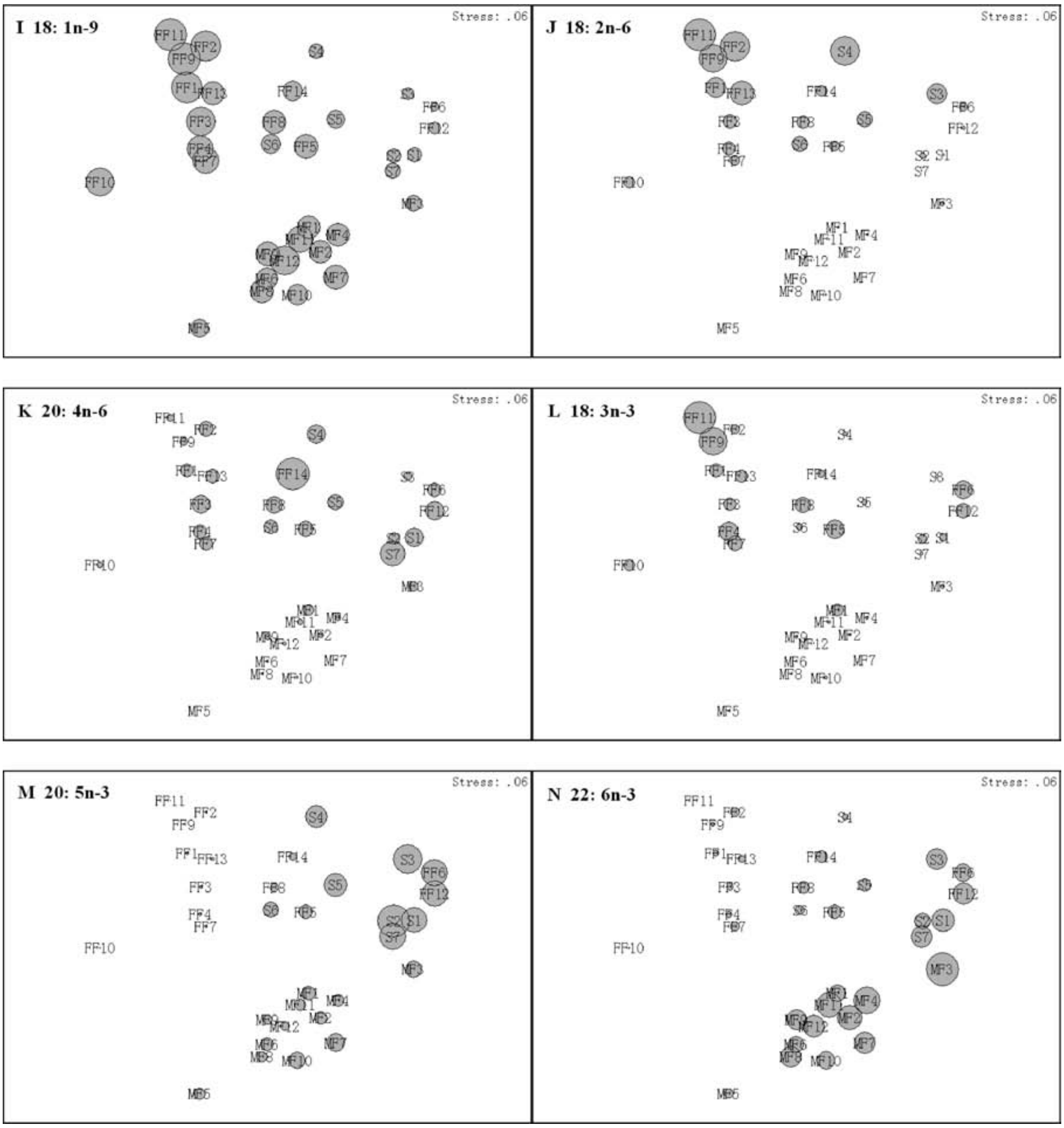

Figure 1. Nonmetric multidimensional scaling (NMDS) ordination plot of fatty acid composition (A) and relative percentages of total SFA (B), MUFA (C), PUFA (D), n-3 PUFA (E), n-6 PUFA (F), n-3/n-6 ratios (G), 16:0 (H), 18:1n-9 (I), 18:2n-6 (J), 20:4n-6 (K), 18:3n-3 (L), 20:5n-3 (M) and 22:6n-3 (N) in the edible meat of fish and shrimps. The positions of the individual samples in the plot (A) indicate their relative degree of similarity based on their fatty acid compositions. The different sizes of gray circles in the plot (B−N) indicate the different relative percentages of the corresponding fatty acids. The larger the size of gray circle is, the higher the relative percentage of the corresponding fatty acid is. MF1 = white herring, MF2 = largehead hairtail, MF3 = melon seed, MF4 = chub mackerel, MF5 = white Chinese croaker, MF6 = spotted maigre, MF7 = bluefin leather jacket, MF8 = small yellow croaker, MF9 = pike eel, MF10 = Bombay duck, MF11 = Spanish mackerel, MF12 = Chinese silver pomfret, FF1 = wild crucian carp, FF2 = cultured crucian carp, FF3 = wild Chinese perch, FF4 = cultured Chinese perch, FF5 = wild bighead carp, FF6 = cultured bighead carp, FF7 = wild snakehead, FF8 = cultured snakehead, FF9 = grass carp, FF10 = common carp, FF11 = black carp, FF12 = silver carp, FF13 = swamp eel, FF14 = Oriental weatherfish, S1 = mantis shrimp, S2 = ridgetail white prawn, S3 = fleshy prawn, S4 = giant freshwater prawn, S5 = whiteleg shrimp, S6 = Oriental river shrimp, S7 = Cipango prawn. The stress value indicates how well the 2-dimensional plot preserves the multidimensional data, with values less than 0.2 indicating a reliable representation.

In order to compare the individual fatty acid composition of the studied fish and shrimps, the relative percentages of some important individual fatty acids were superimposed on the ordination plot (Figure 1B−N), where the size of the shaded area reflects the amount of the corresponding fatty acid proportionally. It is clear that most of the marine fish (groups 5 and 6) had slightly higher levels of total SFA and 16:0, but lower levels of total PUFA than most of the shrimps and freshwater fish (groups 2, 3 and 4) (Figure 1B,D,H). The levels of total MUFA and 18:1n-9 in most of the freshwater fish (groups 2 and 3) were similar to those in most of the marine fish (groups 5 and 6), but slightly higher than those in all shrimps (groups 3 and 4) (Figure 1C,I). However, the differences in the fatty acid composition between the six groups of studied aquatic animals were

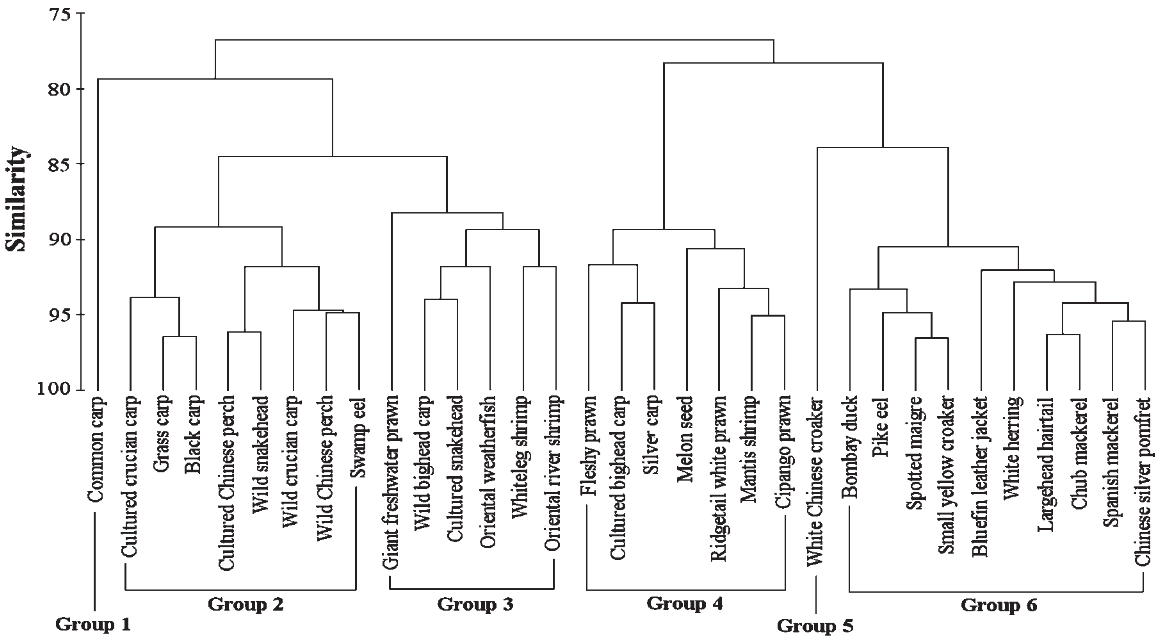

Figure 2. Hierarchical cluster analysis of fatty acid composition in the edible meat of fish and shrimps.

mainly caused by the differences in the levels of total n-3 PUFA (Figure 1E), n-6 PUFA (Figure 1F), n-3/n-6 ratio (Figure 1G), 18:2n-6 (Figure 1J), 20:4n-6 (Figure 1K), 18:3n-3 (Figure 1L), EPA (Figure 1M), and DHA (Figure 1N). Most of the marine fish (group 6) and shrimps (group 4) had much higher total n-3 PUFA but lower n-6 PUFA levels than most of the freshwater fish and shrimps (groups 2 and 3) (Figure 1E,F). All of the studied marine fish (groups 4, 5 and 6), followed by the studied marine shrimps (group 4), displayed the highest levels of n-3/n-6 ratio, while the freshwater fish and shrimps (groups 2 and 3) had the lowest levels of n-3/n-6 ratio (Figure 1G). Özogul et al.[2] found higher levels of total n-3 PUFA and n-3/n-6 ratio, but lower levels of total n-6 PUFA in marine fish than freshwater fish in Turkey. Such differences are mainly attributed to the different fatty acid composition of freshwater and marine phytoplankton, which is the initial n-3 PUFA source of fish and shrimps. Compared with freshwater phytoplankton, marine phytoplankton had much higher n-3 PUFA, EPA, and DHA, but lower n-6 PUFA compositions.[29,30,39] In the present study, all of the studied marine fish and shrimps (groups 4, 5, and 6) presented much higher levels of EPA and DHA, but lower levels of 18:3n-3 than the studied freshwater fish except cultured bighead carp and silver carp (groups 1, 2, and 3) (Figure 1L,M,N). This is partially due to the different PUFA requirement for freshwater and marine fish. It has been reported that marine fish have a strict requirement for long-chain n-3 PUFA, especially EPA and DHA, whereas freshwater fish require 18:3n-3 for the normal growth.[40] Most of the studied freshwater fish (groups 2 and 3), followed by the shrimps (group 3), demonstrated much higher levels of 18:2n-6 and 20:4n-6 than the studied marine fish (groups 5 and 6) (Figure 1J,K). It has been reported that freshwater fish are characterized by high levels of n-6 PUFA, especially 18:2n-6 and 20:4n-6, and low levels of n-3 PUFA, especially EPA and DHA, compared to marine fish.[2,41] This can be explained to some extent by the special diet for freshwater fish. Apart from fish powder, some fresh vegetables and grass, which are rich in 18:3n-3 and 18:2n-6, are also the important diet sources for freshwater fish, especially for herbivorous fish.[32]

In the present study, both the lipid content and fatty acid compositions such as total n-3 and n-6 PUFA, n-3/n-6 ratio, 18:2n-6, 20:4n-6, 18:3n-3, EPA, and DHA were significantly different between species. Compared with most freshwater fish and shrimps, the marine species had higher total n-3 PUFA, EPA, and DHA, but lower total n-6 PUFA, 18:2n-6, and 20:4n-6 compositions. The marine fish, which were high in both lipid content and total n-3 PUFA composition, are the most excellent sources of n-3 PUFA for human health. Though the marine shrimps had comparable total n-3 PUFA, EPA, and DHA compositions to the marine fish, their lipid contents were much lower than fish. Among freshwater fish, bighead carp and silver carp, which were high in lipid content and total n-3 PUFA, EPA and DHA compositions, are also a good choice for people who mainly consume freshwater species.

Since all the fresh aquatic and marine products have to be processed before consuming, further research is warranted to experimentally investigate the effects of some usual processing methods, such as freezing and cooking/heat processing, on the lipid content and fatty acid composition of fish and shrimps. This may be useful and of interest to both aquatic product producers and consumers.

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ABBREVIATIONS USED

BHT, butylated hydroxytoluene; GLC, gas−liquid chromatography; FAME, fatty acid methyl esters; FID, flame ionization detector; SD, standard deviation; NMDS, nonmetric multidimensional scaling; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid

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