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ORIGINAL ARTICLE

Seasonal variations of fatty acid profile in different tissues of farmed bighead carp (*Aristichthys nobilis*)

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Abstract Bighead carp (*Aristichthys nobilis*) is one of the major farmed species of freshwater fish in China. Byproduct volume of bighead carp is significant at up to 60 % of whole fish weight. A better understanding of the nutritional composition is needed to optimize the use of these raw materials. The objective of this research was to characterize seasonal variations of fatty acid profile in different tissues (heads, bones, skin, scales, viscera, muscle and fins) of farmed bighead carp. The fatty acid composition of farmed bighead carp varied significantly with seasons and tissues. The highest lipid content was determined in viscera while the highest EPA and DHA composition were observed in muscle compared to the other tissues. Significantly higher ΣEPA+DHA (%) was recorded in all tissues in summer (June) when compared with those of the other three seasons ($p<0.05$). The n-3/n-6 fatty acid ratios in summer ranged from 3.38 to 3.69, nearly three times the ratios of the other three seasons. The results indicated that farmed bighead carp caught in summer could better balance the n-3 PUFA needs of consumers. The byproducts of bighead carp can be utilized for the production of fish oil.

Keywords Polyunsaturated fatty acids (PUFA) · n-3/n-6 fatty acid ratio · EPA · DHA · Gas chromatography

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Abbreviations

EPA	Eicosapentaenoic acid
DHA	Docosahexaenoic acid
n-3 PUFA	Omega-3 polyunsaturated fatty acids
FAMEs	Fatty acid methyl esters
LA	Linoleic acid
LNA	Linolenic acid
SFA	Saturated fatty acids
MUFA	Monounsaturated fatty acids
HUFA	High polyunsaturated fatty acids

Introduction

A number of previous scientific reports indicated that most biological wastes from fish product processing factories do not deserve to be dumped to waste (Liaset et al. 2000; Mamelona et al. 2010). They should be reclaimed, reprocessed and exploited in different area, notably to produce some value-added products. Actually, these wastes are often rich in natural elements of nutritional importance such as advantageous fatty acid, especially the PUFA. Thus, a better understanding of the nutritional and chemical composition is needed to optimize the use of these raw materials.

Bighead carp (*Aristichthys nobilis*) is one of the main freshwater fish species of commercial interest in inland of China. It was estimated that 2,668,000 t were harvested in 2011 (Fishery Bureau of Ministry of Agriculture of the People's Republic of China 2012). Approximately 60 % of the total weights of bighead carp is produced as biological wastes. Most of them are discarded and sent thereafter to waste disposals or at best processed for fishmeal production. However, much of the oil in byproducts of bighead carp is a potential ideal source of the PUFA. During the last decades, a

great amount of studies have been reported on the significance of PUFA in human nutrition. The n-3 PUFA, especially EPA and DHA have been documented to prevent diseases such as cardiovascular diseases, psoriasis, bowel diseases, cancer, mental illnesses and rheumatoid arthritis, etc. (Narayan et al. 2006; Rubio-Rodríguez et al. 2010). Additionally, DHA is a major component of brain, eye retina and heart muscle. It has been considered as important for brain and eye development (Whelan et al. 1993). Considering all these facts, consuming fish oil rich in n-3 PUFA can not be neglected.

Different fatty acid composition of raw fish byproduct has been evaluated extensively (Swapna et al. 2010). The fatty acid profile of the oil products varies by fish species and the types of waste components used (heads, viscera, skin, frames, trim, etc.) (Wu et al. 2011). Further, differences in the season of catching alter the fatty acid composition of fish and oil made from these materials owing to the size, reproductive cycle of the fish and external factors, such as environmental temperature, salinity and feed (Gökçe et al. 2004; Inhamuns and Franco 2008). In order to maximize the use of the fish processing by-products as advantageous oil products, these differences need to be characterized.

The purpose of the present study was to characterize the seasonal difference of the fatty acid composition between varied tissues of farmed bighead carp. Results are compared to other fish species and intend to serve as a tool for decision making in better utilization of those byproducts.

Materials and methods

Sample preparation

All the commercial-scale farmed bighead carps (n=12) were collected from the same aqua farm (Miyun District) in suburban areas of Beijing during four seasons (March, June, September and December) in 2012. They were raised in ponds, feeding on a commercial formulated feed. The proximate constituents in the feed were as follows: approximately 28 % protein (stemmed from fishmeal, soybean meal and rapeseed meal); 6 % lipids (mostly marine fish oil in origin); 15 % ash, and 12 % fibre (rice bran). As the bighead carp is a kind of filter-feeder fish, they also feed on native phytoplankton, zooplankton in the pond. After collection, the farmed bighead carps were immediately transported to the laboratory alive. The mean weight and length of fish during four seasons were 1502±92.2 g and 43.3±1.32 cm, respectively. Fish was killed by a blow to the head. Then the heads, bones, skin, scales, viscera, muscle and fins were separated and homogenized with a high-speed tissue grinder. The remaining muscle on the bone was removed as much as possible by scraping with a small knife. The homogenates were stored at −18 °C prior to fatty acid analysis.

Chemicals

The BF_3:CH_3OH mixture (14:86, by vol.) was obtained from Sigma–Aldrich Corporation (St. Louis, MO, USA). Standard 37 component FAME mixture was purchased from Supelco Inc. (Bellefonte, PA, USA). All other reagents (chloroform, methanol, hexane, etc.) used in this study were of chemical grade and commercially available.

Proximate composition analysis

Moisture, ash and crude protein contents were determined according to the Association of Official Analytical Chemists procedures (AOAC 1995). Crude fat was determined by a rapid method of total lipid extraction and purification (Bligh and Dyer 1959).

Fatty acid analysis

Extraction of total lipids

Total lipids were extracted by following a minor modified Folch's method (Folch et al. 1957) from homogenized tissues of bighead carp. Briefly, approximately 4 g of sample were extracted overnight with 20 mL of chloroform/methanol (2:1, v/v). The extracts were then filtered and shake with 10 mL of distilled water to get rid of non-lipid substances. The lower phase was collected and evaporated under a stream of nitrogen.

Preparation of fatty acid methyl esters (FAMEs)

Following the AOAC (1995) method, 0.1 g of oil-soluble extract was saponified by heating in a sealed methylating tube with 3 ml of 0.5 M NaOH/methanol in a boiling water bath for 10 min. Following the reaction with alkali, 5 mL of a boron trifluoride: methanol (BF_3:CH_3OH) mixture (14:86, by vol.) were added, and then heated in the boiling water bath for another 2 min. Subsequently, 5 mL of heptane was added to extract the esterified fatty acids. The solution was left to cool to room temperature, and NaCl was then added to a saturated concentration to prevent emulsion. Finally, the heptane-extracted fraction (upper phase) was dried under a stream of nitrogen.

Analysis of lipid composition (FAMEs analysis)

The FAMEs was fully dissolved in 0.1 mL of hexane, and 2 μL of this dissolved solution was injected into a gas chromatograph (GC8600; Beijing Beifen-Tianpu Analytical Instrument (Group) CO., Ltd, Beijing, China) for analysis. The chromatograph was equipped with a SP™-2560 capillary column (100 m×0.25 mm ID.; Supelco Inc., Bellefonte, PA) and a flame ionization detector (FID). Both the injector and

detector temperatures were set at 250 °C. The initial column temperature was 140 °C and held for 5 min, then it was increased by 4 °C/ min to a final temperature of 240 °C and held steady for 40 min. Nitrogen was used as the carrier gas at a flow rate of 1.5 ml/min. The fatty acids were identified by comparing their retention times to a mixture of fatty acid methyl ester standards (37 component FAME mixture). A background spectra without sample injection was acquired and then spectrum stripping was adopted to eliminate the impact of background noise. The composition of fatty acids was expressed in the relative percentage of the total fatty acids according to their peak areas. The relative content of each component was determined by the area normalization method and then calculated by the following equation: Area% FAX = [AX/AR]×100, where: FAX = fatty acid to be quantified, AX = area of the methyl esters X and AR = total area of the chromatogram (Memon et al. 2011).

Statistical analysis

All measurements were carried out in triplicate. Data were subjected to one-way analysis of variance (ANOVA) using the Compare Means Procedure of SPSS Statistics (17.0) (SPSS Inc., Chicago, IL). The least significant difference (LSD) procedure was used to test for difference between means (Differences were considered to be significant when $p<0.05$).

Results and discussion

Proximate composition and proportion of heads, muscle, bones, skin, scales, viscera and fins from farmed bighead carp

Table 1 shows the proximate composition and proportion of the head, muscle, bones, skin, scales, viscera and fins from farmed bighead carp (harvested in March). The muscle accounts for 41.32 % weight of the whole fish, followed by the head (33.37 %). Three other major freshwater species (crucian carp (*Carassius carassius*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*)) have a relatively lower proportion of heads according to our previous research (Hong et al. 2013). The proximate composition of bighead carp differs significantly in the level of moisture, crude proteins, ash and crude fat between tissues. The crude fat content of muscle was 0.55 %, significantly lower than crude fat content of viscera (10.13 %) ($p<0.05$). Fish are often classified into lean fish (fat less than 5 %), medium fat fish (fat 5–10 %) and fatty fish (fat more than 10 % by weight) on the basis of their fat contents (Rahnan et al. 1995). Based on this classification, bighead carp could be characterized as lean fish. The highest crude protein value in bighead carp was observed in skin (24.28 %) and the lowest in viscera (11.70 %). The moisture of fin was the lowest, while no significant difference was determined between head, skin and scale ($p>0.05$). The ash content of bighead carp muscle was very closed to that of the dorsal meat cut of farmed giant catfish (*Pangasianodon gigas*) (1.47 %, wet weight) (Chaijan et al. 2010).

Fatty acid composition

Gas chromatographic analysis of the fatty acids in the total lipid fraction of the fish samples revealed the presence of 27 different fatty acids, 18 of which were unsaturated and 9 that were saturated (Tables 2, 3, 4 and 5). In general, most of fatty acid of different tissues in farmed bighead carp exhibited notable similarities, with relatively high content of polyunsaturated fatty acids (PUFA), predominantly C18:2n6 (linoleic acid, LA), C18:3n3 (linolenic acid, LNA), C20:5n3 (EPA) and C22:6n3 (DHA). The edible part, especially the muscle, shows highest EPA and DHA content when compared with the corresponding content in other tissues. In contrast, Huynh et al. (2007) reported a converse pattern of EPA and DHA in spawning and non-spawning Pacific herring (*Clupea harengus pallasi*). The highest EPA and DHA were determined in their livers and gonad. This phenomenon is attributable in large part to that DHA is an important component of membrane structural lipids (Tocher and Harvie 1988), the relative percentage of this HUFA is expected to increase during the gonad development stage. A lower level of SFA of fish muscle was observed during spring (March), while a

Table 1 Proximate composition and proportion of heads, muscle, bones, skin, scales, viscera and fins of farmed bighead carp (% fresh weight)

	Head	Muscle	Bone	Skin	Scale	Viscera	Fin
Proportion%	33.37 ± 2.23^{c}	41.32 ± 2.79^{d}	7.40 ± 0.53^{b}	2.92 ± 0.24^{a}	2.05 ± 0.23^{a}	6.34 ± 0.13^{b}	3.54 ± 1.12^{a}
Moisture%	70.55 ± 1.30^{c}	78.94 ± 0.10^{e}	66.68 ± 2.36^{b}	71.79 ± 0.39^{cd}	71.38 ± 0.39^{c}	74.23 ± 1.95^{d}	58.25 ± 1.53^{a}
Crude protein%	12.45 ± 2.26^{ab}	17.90 ± 0.36^{d}	14.57 ± 0.99^{bc}	24.28 ± 2.15^{f}	21.64 ± 1.42^{e}	11.70 ± 0.50^{a}	15.27 ± 0.91^{c}
Lipids%	3.48 ± 0.50^{b}	0.55 ± 0.12^{a}	1.27 ± 0.68^{a}	0.88 ± 0.14^{a}	0.11 ± 0.03^{a}	10.13 ± 1.64^{c}	0.67 ± 0.10^{a}
Ash%	8.89 ± 0.69^{b}	1.67 ± 0.35^{a}	8.19 ± 0.26^{b}	0.86 ± 0.20^{a}	9.46 ± 1.66^{b}	0.87 ± 0.089^{a}	17.73 ± 1.64^{c}

Values are expressed as Mean ± SD of triplicate measurements; Least Significant Difference (LSD); Different superscript lowercase letters (a, b, c, d) in same row indicate significant difference at $p<0.05$

Table 2 Fatty acid composition (% of total fatty acids) in the total lipids of muscle from farmed bighead carp

Fatty acids	Spring (March)	Summer (June)	Autumn (September)	Winter (December)
C14:0	2.19±0.08^{a}	2.65±0.13^{a}	2.43±0.08^{a}	2.64±0.56^{a}
C15:0	0.60±0.15^{a}	0.69±0.57^{a}	0.26±0.03^{a}	0.29±0.05^{a}
C16:0	16.19±2.03^{a}	15.22±0.36^{a}	17.18±0.60^{a}	17.83±1.51^{a}
C17:0	0.51±0.27^{a}	1.21±0.23^{b}	0.84±0.34^{a}	1.18±0.08^{b}
C18:0	5.18±0.92^{a}	6.87±0.72^{b}	6.34±0.96^{ab}	5.94±0.26^{ab}
C20:0	0.19±0.07^{a}	0.36±0.06^{b}	0.39±0.02^{b}	0.26±0.13^{ab}
C21:0	0.08±0.07^{ab}	0.06±0.07^{a}	0.17±0.01^{b}	0.14±0.01^{ab}
C22:0	0.31±0.16^{a}	1.95±0.08^{c}	0.71±0.06^{b}	0.50±0.11^{a}
C24:0	0.06±0.04^{a}	0.06±0.02^{a}	0.07±0.03^{a}	0.11±0.07^{a}
ΣSFA	**25.30±0.43^{a}**	**29.07±1.19^{b}**	**28.33±0.59^{b}**	**28.87±2.09^{b}**
C14:1	0.73±0.06^{a}	1.30±0.57^{ab}	0.97±0.11^{a}	1.74±0.21^{b}
C15:1	0.17±0.13^{a}	0.42±0.19^{b}	0.06±0.02^{a}	0.05±0.01^{a}
C16:1	7.10±1.20^{a}	6.26±1.38^{a}	5.40±0.37^{a}	6.20±0.43^{a}
C17:1	0.26±0.19^{a}	0.50±0.01^{a}	0.83±0.15^{b}	1.12±0.16^{c}
C18:1n9	22.07±6.72^{a}	14.91±2.73^{a}	18.72±3.12^{a}	15.63±3.36^{a}
C20:1	1.24±0.17^{ab}	1.10±0.15^{a}	1.45±0.13^{b}	1.20±0.02^{ab}
C22:1n9	0.34±0.17^{a}	0.13±0.01^{a}	0.31±0.18^{a}	0.20±0.01^{a}
C24:1	0.12±0.02^{a}	0.24±0.12^{b}	0.10±0.02^{a}	0.04±0.02^{a}
ΣMUFA	**32.03±7.49^{a}**	**24.87±2.54^{a}**	**27.84±2.93^{a}**	**26.17±2.54^{a}**
C18:2n6 *LA*	8.34±3.10^{b}	2.98±0.37^{a}	11.79±1.57^{c}	6.41±0.33^{b}
C18:3n6	0.53±0.69^{a}	0.38±0.02^{a}	0.36±0.23^{a}	0.49±0.08^{a}
C18:3n3 *LNA*	4.46±0.79^{a}	5.66±0.44^{b}	6.79±0.19^{c}	6.08±0.47^{bc}
C20:2	1.46±0.15^{b}	0.61±0.02^{a}	0.57±0.08^{a}	0.79±0.16^{a}
C20:3n6	0.47±0.20^{a}	0.26±0.09^{a}	0.42±0.20^{a}	0.54±0.07^{a}
C20:3n3	0.72±0.19^{a}	1.14±0.01^{b}	0.76±0.07^{a}	0.91±0.16^{ab}
C20:4n6	2.79±0.66^{a}	2.88±0.49^{a}	2.47±0.61^{a}	4.58±0.69^{b}
C22:2	1.54±0.18^{a}	2.81±0.33^{b}	1.61±0.16^{a}	1.53±0.18^{a}
C20:5n3 *EPA*	6.49±1.86^{ab}	7.76±0.29^{b}	4.62±0.76^{a}	6.54±0.83^{ab}
C22:6n3 *DHA*	5.72±0.95^{a}	9.18±0.87^{b}	5.04±0.94^{a}	6.58±1.36^{a}
ΣPUFA	**32.53±4.28^{a}**	**33.66±1.25^{a}**	**34.78±1.60^{a}**	**33.65±4.43^{a}**
Σn-3	17.40	23.73	17.20	20.10
Σn-6	12.13	6.51	15.40	12.02
n-3/n-6	1.43	3.65	1.12	1.67

Values are expressed as Mean ± SD of triplicate measurements; Least Significant Difference (LSD); Different superscript lowercase letters (a, b, c) in same row indicate significant difference at $p<0.05$

higher proportion of PUFA was observed during summer (June) (Table 2). Similar results were reported by Dal Bosco et al. (2012) for goldfish (*Carassius auratus* L.).

Saturated fatty acids (SFA)

The dominant saturated fatty acid in farmed bighead carp was palmitic acid (C16:0) (ranging from 12 % to 23 % in different tissues), contributing approximately 50.0–69.1 % to the total SFA content during all seasons. Palmitic acid was reported to be abundant since it is a key metabolite in fish and its level is not influenced by the diet (Ackman 1967). This finding agrees with the study on fatty acid profile in flesh of some other freshwater fish species (crucian carp, Chinese perch (*Siniperca chuatsi*), snakehead (*Channa argus*), grass carp, common carp, black carp (*Mylopharyngodon piceus*), silver carp (*Hypophthalmichthys molitrix*), swamp eel (*Monopterus albus*) and oriental weatherfish (*Misgurnus anguillicaudatus*)) (Li et al. 2011). C16:0 content determined in scales was the highest compared to any other tissues during spring (March), autumn (September) and winter (December), while they were determined the lowest in summer (June) (12 %). There were no significant differences between seasons in terms of C16:0 in heads, bones, muscle and fins ($p>0.05$). The highest C16:0 was obtained in scale during spring (23.07 %).

Stearic acid (C18:0) was the second major SFA (3.82~11.32 %). The highest C18:0 was obtained in scales in the spring (March), significantly higher than that in the summer (June) ($p<0.05$). However, Xu et al. (2010) reported a different result that the highest C18:0 was presented in the liver (13~15 %) of Japanese sea bass (*Lateolabrax japonicus*) reared in seawater and freshwater. C15:0, C17:0, C20:0, C21:0, C24:0 were found to be low in SFA fractions of all tissues investigated. Behenic acid (C22:0) obtained in the summer (June) (1.95~3.23 %) in all tissues were the highest compared with their counterpart during the other three seasons ($p<0.05$).

Monounsaturated fatty acids (MUFA)

The total MUFA ranged from 21.80 % to 36.99 % (Tables 2, 3, 4 and 5) in all tissues of bighead carp during the whole year. Bighead carp caught in spring (March) had the highest levels of MUFA in muscle compared with those of the other three seasons. Oleic (C18:1n-9) and palmitoleic (C16:1) acid dominated the MUFA fraction in all tissues of bighead carp and this was similar to MUFA patterns in muscle, gill, and liver of gilthead sea bream (*Sparus aurata*) (Ibarz et al. 2005).

Oleic acid (C18:1n-9) has been reported to be positively correlated with the maximal swimming speed of Atlantic salmon (*Salmo Salar*), indicating that these fatty acids rather than PUFA are the preferred fuels in swimming muscles of fish (McKenzie et al. 1998). The C18:1n-9 in the present study was the most abundant MUFA in all tissues, ranging from 12.24 % to 23.45 %. The highest C18:1n-9 was observed in the viscera obtained during spring (March). This observation suggests that this particular fatty acid is transferred directly from the diet, with greater levels found in the digestive organs (Huynh et al. 2007).

Palmitoleic acid (C16:1) was the second major MUFA (3.31–9.04 %) in all tissues of bighead carp during four seasons and they were lower than the reported C16:1 content of Vimba vimba tenella (16.20–20.01 %) by Kalyoncu et al. (2009).

Table 3 Fatty acid composition (% of total fatty acids) in the total lipids of scale and viscera from farmed bighead carp

Fatty acids	Scale				Viscera			
	Spring (March)	Summer (June)	Autumn (September)	Winter (December)	Spring (March)	Summer (June)	Autumn (September)	Winter (December)
C14:0	2.05±0.17^{bc}	3.10±0.06^{d}	1.56±0.82^{ab}	1.16±0.26^{a}	2.73±0.61^{cd}	3.43±0.63^{de}	2.79±0.14^{cd}	3.96±0.24^{e}
C15:0	1.06±0.84^{b}	0.02±0.18^{a}	0.46±0.37^{bc}	0.18±0.05^{a}	0.07±0.04^{a}	0.33±0.06^{a}	0.30±0.03^{a}	0.46±0.01^{bc}
C16:0	23.07±1.33^{e}	12.01±2.62^{a}	19.11±1.60^{d}	18.23±0.92^{cd}	14.00±1.68^{ab}	15.27±0.70^{b}	16.31±0.94^{bc}	17.93±0.67^{cd}
C17:0	0.61±0.06^{a}	0.58±0.54^{a}	1.11±0.13^{bc}	1.38±0.03^{c}	0.44±0.22^{a}	1.28±0.06^{c}	0.85±0.15^{ab}	1.18±0.06^{bc}
C18:0	11.32±0.55^{b}	4.77±1.34^{a}	10.46±2.89^{b}	9.34±0.83^{b}	3.82±0.46^{a}	6.13±0.89^{a}	5.08±0.17^{a}	4.10±1.81^{a}
C20:0	0.25±0.04^{abc}	0.24±0.05^{ab}	0.48±0.10^{d}	0.15±0.03^{a}	0.13±0.11^{a}	0.34±0.14^{bcd}	0.39±0.02^{cd}	0.47±0.03^{d}
C21:0	0.06±0.04^{a}	0.04±0.03^{a}	0.13±0.06^{abc}	0.12±0.05^{abc}	0.17±0.05^{bc}	0.10±0.01^{abc}	0.18±0.04^{c}	0.08±0.08^{ab}
C22:0	0.20±0.02^{a}	3.23±0.53^{e}	0.55±0.17^{abc}	0.17±0.12^{a}	0.32±0.18^{ab}	2.44±0.08^{d}	0.85±0.02^{c}	0.62±0.18^{bc}
C24:0	0.43±0.53^{b}	0.06±0.00^{ab}	0.11±0.08^{ab}	0.22±0.07^{ab}	0.05±0.02^{a}	0.07±0.01^{ab}	0.05±0.00^{a}	0.13±0.00^{ab}
ΣSFA	**39.04±0.63^{e}**	**24.05±4.25^{ab}**	**33.98±3.41^{c}**	**30.95±1.62^{c}**	**22.05±0.38^{a}**	**29.36±1.08^{c}**	**26.80±1.04^{bc}**	**28.93±1.49^{c}**
C14:1	0.95±0.08^{a}	1.49±0.33^{a}	1.85±1.70^{a}	1.72±0.09^{a}	1.09±0.35^{a}	1.11±0.16^{a}	1.13±0.04^{a}	2.07±0.09^{a}
C15:1	0.03±0.02^{a}	0.28±0.01^{d}	0.28±0.06^{d}	0.16±0.13^{bc}	0.09±0.01^{ab}	0.20±0.07^{cd}	0.04±0.03^{a}	0.07±0.03^{ab}
C16:1	6.88±0.20^{cd}	7.29±0.55^{cd}	3.31±1.81^{a}	4.56±0.36^{ab}	8.62±0.84^{de}	7.11±0.95^{cd}	6.15±0.30^{bc}	9.04±1.26^{e}
C17:1	0.69±0.39^{ab}	0.64±0.11^{ab}	0.38±0.33^{a}	1.11±0.13^{cd}	0.56±0.15^{ab}	0.51±0.04^{ab}	0.82±0.09^{bc}	1.39±0.05^{d}
C18:1n9	12.24±0.32^{a}	17.76±1.73^{ab}	23.01±4.19^{b}	14.86±1.40^{a}	23.45±5.56^{b}	15.17±1.27^{a}	21.92±4.37^{b}	13.81±1.88^{a}
C20:1	0.44±0.11^{a}	1.46±0.29^{bc}	0.56±0.57^{ab}	0.60±0.42^{abc}	1.61±1.26^{c}	1.16±0.12^{abc}	1.56±0.13^{bc}	1.42±0.09^{abc}
C22:1n9	0.11±0.02^{a}	0.32±0.12^{ab}	0.11±0.04^{a}	0.61±0.45^{b}	0.30±0.08^{a}	0.13±0.07^{a}	0.20±0.03^{a}	0.23±0.04^{a}
C24:1	0.45±0.16^{d}	0.28±0.06^{c}	0.14±0.07^{ab}	0.63±0.05^{e}	0.15±0.05^{abc}	0.20±0.02^{bc}	0.06±0.04^{a}	0.17±0.01^{abc}
ΣMUFA	**21.80±0.26^{a}**	**29.52±3.21^{bc}**	**28.69±2.44^{bc}**	**24.25±1.15^{ab}**	**36.87±4.81^{d}**	**25.58±2.15^{ab}**	**31.02±2.68^{c}**	**28.20±0.80^{bc}**
C18:2n6 *LA*	7.12±0.37^{ab}	4.01±0.48^{a}	13.34±4.45^{cd}	3.63±0.69^{a}	10.32±3.24^{bc}	3.32±0.30^{a}	14.01±0.65^{d}	7.08±0.84^{ab}
C18:3n6	1.30±0.53^{bc}	0.46±0.01^{a}	0.75±0.41^{abc}	0.58±0.20^{ab}	1.46±0.96^{c}	0.48±0.01^{a}	0.40±0.15^{a}	0.54±0.22^{ab}
C18:3n3 *LNA*	2.21±0.74^{a}	7.17±0.27^{b}	3.23±2.13^{a}	2.33±1.06^{a}	6.30±1.59^{b}	6.96±0.19^{b}	7.88±0.23^{b}	7.80±0.31^{b}
C20:2	1.13±0.10^{c}	0.36±0.20^{a}	0.66±0.17^{b}	0.85±0.10^{b}	1.74±0.14^{d}	0.66±0.03^{b}	0.74±0.12^{b}	0.80±0.15^{b}
C20:3n6	0.27±0.13^{b}	0.43±0.08^{c}	0.49±0.07^{c}	0.12±0.04^{a}	0.55±0.10^{c}	0.40±0.13^{bc}	0.50±0.03^{c}	0.56±0.04^{c}
C20:3n3	0.66±0.18^{abc}	1.31±0.07^{d}	0.47±0.17^{ab}	0.42±0.56^{a}	0.91±0.25^{bcd}	1.27±0.11^{d}	0.80±0.04^{abc}	1.08±0.07^{cd}
C20:4n6	4.37±0.31^{c}	1.93±0.06^{a}	2.99±0.63^{b}	8.30±0.91^{d}	1.73±0.63^{a}	1.89±0.08^{a}	1.41±0.06^{a}	2.96±0.16^{b}
C22:2	0.85±0.25^{a}	3.46±0.17^{d}	0.96±0.29^{a}	0.98±0.22^{a}	1.84±0.52^{c}	3.26±0.12^{d}	1.75±0.05^{b}	1.89±0.06^{bc}
C20:5n3 *EPA*	4.07±0.10^{ab}	7.33±0.15^{d}	2.72±0.64^{a}	4.58±0.32^{bc}	4.76±1.35^{bc}	7.05±0.23^{d}	3.72±0.15^{b}	4.97±0.20^{c}
C22:6n3 *DHA*	4.56±0.27^{b}	7.29±0.08^{c}	3.47±0.60^{a}	7.20±0.28^{c}	2.88±0.63^{a}	7.21±0.66^{c}	3.04±0.23^{a}	4.35±0.20^{b}
ΣPUFA	**26.54±1.24^{a}**	**33.75±1.07^{d}**	**29.46±0.70^{ab}**	**28.14±1.21^{bc}**	**30.80±4.78^{a}**	**32.50±1.47^{d}**	**34.61±1.27^{d}**	**31.22±1.59^{cd}**
Σn-3	11.49	23.10	9.88	14.53	14.84	22.49	15.43	18.20
Σn-6	13.06	6.83	17.96	12.63	14.06	6.09	16.69	11.14
n-3/n-6	0.88	3.38	0.55	1.15	1.06	3.69	0.92	1.63

Values are expressed as Mean ± SD of triplicate measurements; Least Significant Difference (LSD); Different superscript lowercase letters (a, b, c, d, e) in same row indicate significant difference at $p<0.05$

C16:1 in autumn (September) was lower than those of the other three seasons in heads, bones, skin, viscera, muscle and fins. C15:1, C17:1, C22:1n9 and C24:1 contributed a small fraction to MUFA.

Polyunsaturated fatty acids (PUFA)

The amount of PUFA ranged from the lowest value 26.54 % in scales in the spring (March) to 37.03 % in fin in autumn (September). The highest percentage of PUFA was noted in muscle (32.53~34.78 %) during four seasons except PUFA in fins in autumn (September). Similar amount of PUFA were also reported for meat of common two-banded seabream (*Diplodus vulgaris*) (34.03 %), sand smelt (*Atherina boyeri*) (34.70 %) and black goby (*Gobius niger*) (34.24 %) (Prato and Biandolino 2012), while significantly higher percentage of PUFA were observed in zander (*Sander lucioperca*) (50.2–57.0 %) (Guler et al. 2007).

The PUFA was mainly composed of n-3 and n-6 PUFA. All examined tissues contained higher proportions of n-3 PUFA

Table 4 Fatty acid composition (% of total fatty acids) in the total lipids of skin and fin from farmed bighead carp

Fatty acids	Skin				Fin			
	Spring (March)	Summer (June)	Autumn (September)	Winter (December)	Spring (March)	Summer (June)	Autumn (September)	Winter (December)
C14:0	2.73±0.67^{a}	3.06±0.43^{ab}	2.86±0.32^{ab}	4.04±0.80^{c}	2.47±0.67^{a}	3.72±0.34^{bc}	2.59±0.23^{a}	3.42±0.15^{abc}
C15:0	0.22±0.25^{a}	0.39±0.14^{a}	0.30±0.06^{a}	0.34±0.00^{a}	0.17±0.14^{a}	0.35±0.09^{a}	0.28±0.06^{a}	0.39±0.02^{a}
C16:0	15.12±0.75^{ab}	14.05±0.78^{a}	17.22±0.80^{b}	17.83±0.83^{b}	16.36±4.12^{ab}	15.64±0.22^{ab}	15.75±0.74^{ab}	17.41±0.52^{b}
C17:0	0.59±0.09^{a}	1.10±0.23^{b}	0.45±0.31^{a}	1.09±0.05^{b}	0.63±0.22^{a}	1.24±0.09^{b}	0.57±0.17^{a}	1.34±0.07^{b}
C18:0	4.32±1.17^{a}	5.46±0.29^{a}	5.23±0.20^{a}	5.27±0.03^{a}	4.87±0.96^{a}	4.65±0.07^{a}	4.38±0.83^{a}	4.56±0.14^{a}
C20:0	0.18±0.14^{ab}	0.36±0.05^{b}	0.39±0.01^{b}	0.33±0.14^{ab}	0.13±0.03^{a}	0.33±0.13^{ab}	0.39±0.06^{b}	0.22±0.18^{ab}
C21:0	0.13±0.15^{a}	0.20±0.14^{a}	0.18±0.05^{a}	0.20±0.02^{a}	0.29±0.26^{a}	0.10±0.00^{a}	0.07±0.04^{a}	0.14±0.02^{a}
C22:0	0.34±0.04^{a}	2.26±0.43^{c}	0.86±0.14^{b}	0.66±0.04^{ab}	0.33±0.16^{a}	2.19±0.24^{c}	0.82±0.15^{b}	0.58±0.03^{ab}
C24:0	0.10±0.06^{a}	0.09±0.05^{a}	0.05±0.01^{a}	0.10±0.03^{a}	0.13±0.11^{a}	0.07±0.02^{a}	0.04±0.01^{a}	0.12±0.04^{a}
ΣSFA	**23.75±1.77^{a}**	**26.95±1.79^{bc}**	**27.55±0.69^{bc}**	**29.85±1.35^{c}**	**25.37±3.20^{abc}**	**28.31±0.89^{bc}**	**24.90±1.86^{ab}**	**28.18±0.87^{bc}**
C14:1	1.02±0.22^{a}	1.07±0.10^{a}	1.18±0.10^{ab}	1.80±0.05^{c}	1.11±0.25^{ab}	1.42±0.14^{b}	0.98±0.23^{a}	2.59±0.23^{d}
C15:1	0.08±0.02^{ab}	0.19±0.16^{bc}	0.03±0.02^{a}	0.06±0.04^{a}	0.27±0.05^{c}	0.07±0.02^{a}	0.01±0.01^{a}	0.09±0.03^{ab}
C16:1	8.47±0.92^{c}	7.46±1.13^{bc}	6.52±0.35^{ab}	7.83±0.30^{c}	7.71±1.02^{bc}	8.16±0.37^{c}	5.96±0.13^{a}	8.12±0.26^{c}
C17:1	0.50±0.18^{ab}	0.38±0.37^{a}	0.76±0.07^{abc}	1.10±0.25^{cd}	0.86±0.56^{abc}	0.78±0.03^{abc}	0.91±0.16^{bc}	1.57±0.16^{d}
C18:1n9	23.18±5.86^{b}	20.28±3.10^{ab}	20.44±2.79^{ab}	19.02±1.55^{ab}	22.17±5.32^{b}	14.72±2.89^{a}	20.65±3.60^{ab}	15.09±1.30^{a}
C20:1	2.80±0.37^{b}	1.28±0.09^{a}	1.57±0.14^{a}	1.49±0.09^{a}	2.76±0.61^{b}	1.03±0.08^{a}	1.44±0.09^{a}	1.13±0.09^{a}
C22:1n9	0.55±0.30^{c}	0.11±0.02^{a}	0.21±0.06^{ab}	0.20±0.06^{ab}	0.37±0.06^{bc}	0.15±0.02^{ab}	0.18±0.03^{ab}	0.18±0.07^{ab}
C24:1	0.38±0.46^{a}	0.24±0.05^{a}	0.08±0.08^{a}	0.25±0.00^{a}	0.21±0.25^{a}	0.15±0.03^{a}	0.03±0.00^{a}	0.26±0.05^{a}
ΣMUFA	**36.99±5.14^{c}**	**29.01±4.54^{a}**	**30.79±1.10^{ab}**	**31.76±0.57^{abc}**	**35.47±3.39^{bc}**	**26.48±2.91^{a}**	**30.16±3.01^{ab}**	**29.04±0.89^{a}**
C18:2n6 *LA*	8.93±3.61^{bc}	3.30±0.47^{a}	11.37±1.88^{c}	6.01±0.67^{ab}	10.45±3.30^{c}	3.51±0.38^{a}	17.15±3.18^{d}	5.61±0.74^{ab}
C18:3n6	0.33±0.07^{a}	0.51±0.05^{bcd}	0.55±0.08^{cd}	0.68±0.02^{d}	0.36±0.19^{ab}	0.58±0.05^{cd}	0.45±0.13^{abc}	0.65±0.06^{d}
C18:3n3 *LNA*	5.77±0.88^{a}	6.53±1.07^{abc}	7.43±0.47^{c}	6.77±0.24^{abc}	5.70±1.20^{ab}	7.61±0.81^{c}	7.62±0.51^{bc}	6.98±0.26^{abc}
C20:2	1.65±0.12^{d}	0.64±0.09^{abc}	0.58±0.06^{ab}	0.80±0.08^{bc}	1.72±0.26^{d}	0.37±0.29^{a}	0.60±0.07^{ab}	0.91±0.13^{c}
C20:3n6	0.46±0.08^{ab}	0.36±0.10^{a}	0.52±0.03^{ab}	0.49±0.04^{ab}	0.59±0.28^{b}	0.33±0.08^{a}	0.48±0.01^{ab}	0.50±0.02^{ab}
C20:3n3	0.81±0.22^{ab}	1.23±0.01^{c}	0.81±0.11^{ab}	0.90±0.09^{ab}	0.87±0.39^{ab}	1.10±0.02^{bc}	0.69±0.08^{a}	0.96±0.07^{abc}
C20:4n6	1.84±0.88^{a}	1.77±0.26^{a}	1.97±0.25^{ab}	2.69±0.30^{b}	1.78±0.58^{a}	2.29±0.15^{ab}	1.45±0.46^{a}	4.06±0.28^{c}
C22:2	1.82±0.37^{b}	3.01±0.27^{c}	1.76±0.23^{b}	1.73±0.05^{b}	1.60±0.33^{a}	2.93±0.18^{c}	1.57±0.22^{ab}	1.43±0.02^{ab}
C20:5n3 *EPA*	4.82±1.16^{ab}	6.60±0.16^{c}	4.20±0.49^{ab}	4.11±0.40^{ab}	4.87±1.21^{ab}	7.60±0.36^{c}	3.75±0.65^{a}	5.28±0.08^{b}
C22:6n3 *DHA*	2.76±0.55^{a}	7.20±0.47^{e}	3.43±0.15^{b}	3.49±0.23^{b}	2.50±0.11^{a}	6.51±0.37^{d}	3.12±0.46^{ab}	4.58±0.35^{c}
ΣPUFA	**29.19±3.39^{ab}**	**31.15±1.68^{bc}**	**32.82±1.09^{bc}**	**26.86±1.44^{a}**	**30.44±2.38^{abc}**	**32.84±1.53^{cd}**	**37.03±1.61^{d}**	**30.04±1.34^{abc}**
Σn-3	14.16	21.57	15.87	15.27	13.94	22.82	15.18	17.80
Σn-6	11.56	5.94	14.61	9.87	13.19	6.71	19.69	10.82
n-3/n-6	1.22	3.63	1.09	1.55	1.06	3.40	0.79	1.65

Values are expressed as Mean ± SD of triplicate measurements; Least Significant Difference (LSD); Different superscript lowercase letters (a, b, c, d, e) in same row indicate significant difference at $p<0.05$

than those of n-6 PUFA. A dietary intake of fish with high n-3/n-6 ratio would be beneficial as people in modernized society tend to intake more n-6 PUFA (Memon et al. 2011). However, wild longsnout catfish (*Leiocassis longirostris*) contained a larger proportion of n-6 PUFA than n-3 PUFA (Wang et al. 2012) which may be due to the fact that wild environment provides a good source of n-6 PUFA.

The major contributor to n-3 PUFA was DHA (C22:6n-3), followed by EPA (C20:5n-3), that together accounted for 56.16–71.38 % (muscle), 62.29–81.07 % (scales), 43.81–63.41 % (viscera), 48.08–63.98 % (skin), 45.26–61.83 % (fins), 43.51–62.93 % (bones), 45.46–62.53 % (heads) of the total n-3 PUFA. Significant higher value (over 70 %) was reported for salema (*Sarpa salpa*), bogue (*Boops boops*),

Table 5 Fatty acid composition (% of total fatty acids) in the total lipids of bone and head from farmed bighead carp

Fatty acids	Bone				Head			
	Spring (March)	Summer (June)	Autumn (September)	Winter (December)	Spring (March)	Summer (June)	Autumn (September)	Winter (December)
C14:0	2.50±0.57^{a}	3.20±0.04^{a}	3.21±0.04^{a}	3.16±0.67^{a}	3.27±1.31^{a}	3.47±0.49^{a}	2.80±0.39^{a}	3.61±0.08^{a}
C15:0	0.07±0.02^{a}	0.10±0.06^{a}	0.35±0.08^{cd}	0.17±0.21^{abc}	0.10±0.03^{a}	0.15±0.15^{ab}	0.31±0.04^{bcd}	0.37±0.01^{d}
C16:0	17.72±4.68^{a}	14.33±0.90^{a}	16.20±2.38^{a}	17.01±1.33^{a}	16.29±0.97^{a}	15.08±0.42^{a}	16.78±0.55^{a}	17.73±0.45^{a}
C17:0	0.90±0.69^{abc}	1.21±0.03^{bc}	0.76±0.28^{ab}	1.18±0.07^{bc}	0.41±0.11^{a}	1.27±0.03^{bc}	0.67±0.09^{a}	1.30±0.04^{c}
C18:0	4.88±2.24^{a}	4.83±0.16^{a}	4.64±0.71^{a}	4.63±0.08^{a}	3.88±0.74^{a}	5.32±0.17^{a}	5.17±0.54^{a}	4.81±0.39^{a}
C20:0	0.21±0.23^{ab}	0.42±0.07^{c}	0.40±0.04^{bc}	0.25±0.15^{abc}	0.19±0.06^{a}	0.31 ±0.06^{abc}	0.40±0.02^{bc}	0.44±0.02^{c}
C21:0	0.05±0.06^{a}	0.03±0.03^{a}	0.11±0.08^{a}	0.10±0.08^{a}	0.10±0.12^{a}	0.13±0.05^{ab}	0.29±0.20^{b}	0.15±0.00^{ab}
C22:0	0.33±0.15^{a}	2.34±0.04^{c}	0.88±0.05^{b}	0.74±0.04^{b}	0.19±0.09^{a}	2.24±0.23^{c}	0.81±0.09^{b}	0.71±0.02^{b}
C24:0	0.07±0.01^{ab}	0.07±0.02^{ab}	0.05±0.01^{a}	0.11±0.04^{b}	0.07±0.01^{ab}	0.05±0.03^{a}	0.05±0.00^{a}	0.10±0.03^{b}
ΣSFA	**26.74±8.52^{a}**	**26.52±1.18^{b}**	**26.58±3.17^{b}**	**27.36±2.27^{b}**	**24.48±2.91^{ab}**	**28.01±0.69^{b}**	**27.27±1.17^{b}**	**29.23±0.11^{b}**
C14:1	1.08±0.29^{a}	1.23±0.14^{a}	1.29±0.13^{a}	1.97±0.30^{b}	1.25±0.29^{a}	1.30±0.18^{a}	1.09±0.21^{a}	2.25±0.08^{b}
C15:1	0.08±0.03^{a}	0.13±0.03^{a}	0.02±0.01^{a}	0.03±0.01^{a}	0.53±0.15^{b}	0.12±0.06^{a}	0.02±0.00^{a}	0.07±0.04^{a}
C16:1	7.44±0.90^{bcd}	7.09±0.26^{abc}	6.60±0.21^{ab}	7.84±0.73^{cd}	8.52±1.27^{d}	7.33±0.20^{bcd}	5.94±0.37^{a}	8.03±0.36^{cd}
C17:1	0.44±0.13^{a}	0.69±0.03^{a}	0.86±0.13^{a}	0.88±0.73^{a}	0.64±0.35^{a}	0.65±0.07^{a}	0.80±0.09^{a}	1.27±0.07^{a}
C18:1n9	22.47±6.90^{c}	17.34±0.62^{abc}	19.57±1.08^{a}	17.06±0.33^{abc}	21.60±2.79^{bc}	16.67±2.75^{ab}	20.65±2.62^{bc}	15.28±1.40^{a}
C20:1	2.56±0.10^{c}	1.11±0.04^{a}	1.56±0.11^{ab}	1.41±0.16^{ab}	1.84±0.78^{b}	1.21±0.09^{a}	1.54±0.12^{ab}	1.30±0.06^{a}b
C22:1n9	0.29±0.09^{c}	0.17±0.04^{ab}	0.21±0.04^{bc}	0.23±0.04^{bc}	0.18±0.07^{ab}	0.09±0.02^{a}	0.17±0.01^{ab}	0.20±0.04^{bc}
C24:1	0.08±0.02^{ab}	0.10±0.03^{ab}	0.05±0.01^{a}	0.16±0.04^{c}	0.06±0.04^{ab}	0.11±0.04^{bc}	0.05±0.01^{a}	0.11±0.03^{abc}
ΣMUFA	**34.44±7.16^{b}**	**27.86±0.76^{ab}**	**30.17±1.16^{ab}**	**29.58±1.58^{ab}**	**34.63±8.67^{b}**	**27.48±2.90^{a}**	**30.25±2.18^{ab}**	**28.49±1.10^{ab}**
C18:2n6 *LA*	9.64±3.81^{bc}	3.46±0.46^{a}	13.94±1.19^{cd}	6.76±0.24^{ab}	11.23±3.64^{cd}	3.48±0.42^{a}	14.70±1.62^{d}	7.08±0.25^{ab}
C18:3n6	0.31±0.03^{a}	0.59±0.03^{a}	0.44±0.14^{a}	0.72±0.09^{a}	0.76±0.88^{a}	0.61±0.05^{a}	0.56±0.04^{a}	0.72±0.05^{a}
C18:3n3 *LNA*	5.95±0.94^{ab}	6.70±0.22^{abc}	8.15±0.64^{c}	7.85±0.32^{c}	5.73±1.57^{a}	7.09±0.76^{abc}	7.40±0.57^{bc}	7.86±0.27^{c}
C20:2	1.72±0.16^{a}	0.39±0.28^{a}	0.55±0.02^{a}	0.93±0.11^{a}	1.71±0.50^{a}	0.63±0.01^{a}	0.46±0.31^{a}	0.91±0.06^{a}
C20:3n6	0.46±0.01^{bc}	0.35±0.01^{ab}	0.46±0.06^{bc}	0.57±0.11^{c}	0.54±0.14^{c}	0.33±0.01^{a}	0.47±0.03^{bc}	0.50±0.01^{c}
C20:3n3	0.75±0.07^{a}	1.01±0.04^{bc}	0.81±0.07^{ab}	1.04±0.12^{c}	0.75±0.26^{a}	1.14±0.06^{c}	0.78±0.09^{a}	1.01±0.06^{bc}
C20:4n6	1.54±0.22^{a}	1.71±0.03^{ab}	1.49±0.16^{a}	2.86±0.23^{c}	1.65±0.57^{ab}	2.09±0.17^{b}	1.58±0.24^{a}	3.06±0.15^{c}
C22:2	1.71±0.24^{a}	2.85±0.15^{b}	1.73±0.17^{a}	1.76±0.24^{a}	1.84±0.56^{a}	2.94±0.23^{b}	1.61±0.14^{a}	1.66±0.12^{a}
C20:5n3 *EPA*	4.67±0.75^{a}	6.96±0.44^{b}	3.90±0.37^{a}	5.32±0.61^{a}	5.13±2.01^{a}	7.13±0.49^{b}	3.83±0.40^{a}	5.30±0.35^{a}
C22:6n3 *DHA*	2.55±0.11^{a}	6.13±0.20^{d}	3.01±0.29^{ab}	3.99±0.84^{c}	2.94±1.13^{ab}	6.62±0.37^{d}	2.98±0.10^{ab}	3.79±0.25^{bc}
ΣPUFA	**29.30±1.33^{a}**	**30.15±0.94^{ab}**	**34.91±2.92^{b}**	**30.88±2.94^{ab}**	**32.29±4.55^{ab}**	**32.06±2.31^{ab}**	**34.45±1.01^{b}**	**30.97±0.78^{ab}**
Σn-3	13.92	20.80	15.88	18.20	14.55	21.99	14.98	17.96
Σn-6	11.95	6.11	16.76	10.92	14.19	6.50	17.40	11.35
n-3/n-6	1.16	3.40	0.95	1.67	1.03	3.38	0.86	1.58

Values are expressed as Mean ± SD of triplicate measurements; Least Significant Difference (LSD); Different superscript lowercase letters (a, b, c, d) in same row indicate significant difference at $p<0.05$

common two-banded seabream and sand smelt (Prato and Biandolino 2012). The ΣEPA+DHA (%) of all bighead carp tissues in summer (June) were the highest compared with those of the other three seasons ($p<0.05$) (Fig. 1). This could be explained by the fact that the farmed bighead carp consumed a larger quantity of freshwater phytoplankton and zooplankton, which was rich in n-3 PUFA, in summer (June) than other seasons. Gökçe et al. (2004) also reported higher ΣEPA+DHA in female common sole (*Solea Solea)* during the summer than the other three seasons. The lowest ΣEPA+DHA were presented in autumn (September) (6.20–9.65 %), but still being higher than those of another three kinds of freshwater fish: grass carp (4.5 %), common carp (2.6 %) and black carp (1.3 %) (Li et al. 2011). The amount of ΣEPA+DHA in the edible part (muscle) of bighead carp was higher than those of other tissues.

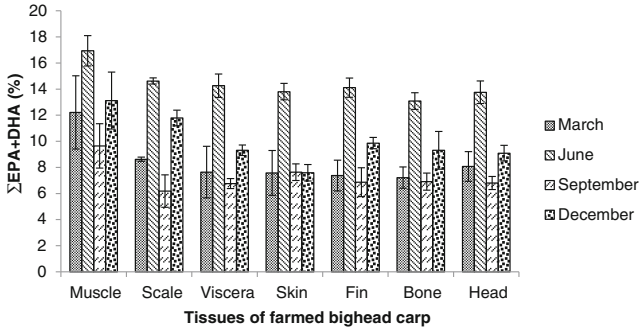

Fig. 1 ΣEPA+DHA (%) in different tissues (muscle, scales, viscera, skin, fins, bones and heads) of farmed bighead carp during four seasons

The most abundant n-6 PUFA was linoleic acid (C18:2n-6), which is the highest in autumn (September) (ranging from 11.37 % to 14.70 %) as compared to those of the other three seasons (Tables 2, 3, 4 and 5). Huynh and Kitts (2009) observed that comparatively low C18:2n-6 (ranging from 0.85 % to 1.5 %) were determined in eight kinds of pacific fish species, including Walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea harengus pallasi*), capelin (*Mallotus villosus*), hake (*Merluccius productus*), canary rock fish (*Sebastes pinniger*), sardine (*Sardinops sagax*), surf smelt (*Hypomesus pretiosus*) and pink salmon (*Onchorhynchus gorbuscha*). However, similar amount of C18:2n-6 (6.3–18.4 %) was reported in accordance with present results for eight kinds of freshwater species: crucian carp, Chinese perch, snakehead, grass carp, common carp, black carp, swamp eel and Oriental weatherfish (Li et al. 2011). Accordingly, we can draw a conclusion that freshwater species possibly possess larger amounts of C18:2n-6 than mostly marine species.

Arachidonic acid (C20:4n-6) was the second major n-6 PUFA in all tissues of bighead carp during four seasons. Similar to EPA and DHA, C20:4n-6 is involved in maintaining cell membrane structure and function and also contributed to reproductive systems in fish (Cejas et al. 2004). C20:4n-6 was lower than either EPA or DHA in heads, bones, skin, viscera, muscle and fins during the whole year but it cannot be neglected in fish due to its important role in a variety of physiological functions including osmoregulation and cardiovascular function (Cejas et al. 2004).

Pigott and Tucker (1990) proposed that the n-3/n-6 ratio is a useful indicator for comparing the relative nutritional value of fish of different species. An increase in the human dietary n-3/n-6 fatty acid ratio helps to prevent cardiovascular disease due to strong anti-inflammatory effects of n-3 fatty acids (Simopoulos 2008). The ratio of n-3/n-6 PUFA in total lipids of bighead carp varied from four seasons. The n-3/n-6 fatty acid ratios in summer (June) were nearly three times the ratios of the other three seasons in all tissues (Tables 2, 3, 4 and 5). These high n-3/n-6 fatty acid ratios were the result of high ΣEPA+DHA in summer (June). Dal Bosco et al. (2012) also observed that the highest n-3/n-6 fatty acid ratios occurred in the summer (June) for goldfish (*Carassius auratus L.*). Thus, the farmed bighead carp caught in the summer (June) is of high nutritional value for human consumption by balancing n-3/n-6 ratio in the usual diet.

Comparison of SFA, MUFA and PUFA

The PUFA was the highest in the muscle of bighead carp in spring, summer, winter and autumn, compared with MUFA and SFA which was in agreement with a similar study carried out by Li et al. (2011). The highest level of PUFA was observed in the scale during spring as a result of dominated EPA and DHA, while the SFA were the most abundant fatty acids during spring, autumn and winter. MUFA contents were higher than both of the SFAs and PUFAs in viscera, bone, head, skin and fin during spring,respectively. As reported by Guler et al. (2007), freshwater fish such as zander partially preferred to accumulate PUFA rather than SFA and MUFA in the richer feeding period. This is in agreement with our finding that the highest PUFA occurred in the muscle of bighead carp in summer. We can attribute this to the fact that bighead carp is a typical filter-feeder fish. They consume more phytoplankton and zooplankton whose development is particularly abundant during summer in fresh water. Furthermore, the phytoplankton and zooplankton are the main source of PUFA for fish, especially long-chain n-3 PUFA (EPA and DHA) (Sahena et al. 2009).

Conclusion

This study represented a step towards the characterization and distribution of seasonal fatty acid profile of the whole bighead carp. The muscle of bighead carp was the most excellent sources of n-3 PUFA in the whole fish which could balanced fatty acid intake of today's consumers. The best fatty acid signature of farmed bighead carp was obtained in the summer and it is proposed that the number of fish caught during this period should be increased. These results could be of practical value from a nutrition perspective for populations who consume these fish.

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