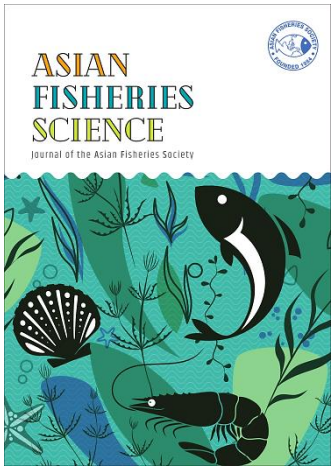

Fillet Quality of Asian Seabass *Lates calcarifer* (Bloch, 1790) Grown in Monoculture and Co-culture Systems in Freshwater Earthen-ponds

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Abstract

The effects of monoculture and co-culture systems on Asian seabass *Lates calcarifer* (Bloch, 1790) fillet composition, fatty acid profile, and chemical taste taint were investigated. The monoculture (T1) and co-culture (T2 and T3) systems with Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758) were carried out in 30 m^2 freshwater earthen ponds for 6 months. Fish in T1 and T3 system were fed daily, and in T2 system was fed every other day. Fish from the co-culture system with Asian seabass and Nile tilapia (T2) had significantly higher protein level (80.8 %), eicosapentaenoic acid (EPA; 1 $mg.g^{-1}$) and significantly lower fat content (5.2 %) than the other treatments. In terms of chemical taste taint, T2 had significantly lower 2-methyl-isoborneol (0.0120 $\mu g.kg^{-1}$) than T1, as well as an absence of geosmin in T2. Meanwhile, Asian seabass from the monoculture system (T1) had significantly higher total fatty acid content (103.82 $mg.g^{-1}$) than T2 and T3. Thus using co-culture system in freshwater earthen ponds, with a feeding interval of 2 days, results in an improved fillet quality of Asian seabass.

Keywords: *Lates calcarifer*, proximate composition, fatty acid, 2-methyl-isoborneol, geosmin

Introduction

Asian seabass *Lates calcarifer* (Bloch, 1970) is one of the most important species and has one of the highest economic values in Thai aquaculture. The Asian seabass has a fast growth rate, high feed conversion, and tolerance to a wide range of environmental conditions. It is a highly-priced species due to its good taste. Its flesh has a reputation for having premium edible properties, including being tender, white, firm, mild-tasting, and having boneless fillets (New South Wales Department of Primary Industries, 2011). Moreover, Asian seabass flesh contains polyunsaturated fatty acids (PUFAs) enriched with omega-3 fatty acids, which help to reduce blood cholesterol levels and prevent hyperlipidemia, secondary cardiovascular disease, and high blood pressure (Pervin et al., 2012). The qualities of good taste, nutritional properties, and a fast growth rate make Asian seabass an excellent study species for aquaculture.

Asian seabass is a euryhaline fish species inhabiting freshwater and returns to seawater to spawn. The culture of Asian seabass in freshwater earthen ponds in Thailand has been successfully demonstrated, and the number of intensive freshwater Asian seabass farms is increasing annually (Kayansamruaj et al., 2017). However, some disadvantages hinder the establishment of Asian seabass farms due to the high input cost and meat quality. A repulsive odour or taste of the fish meat may cause a major reduction in their consumption (Vallod et al., 2007). One possible way of dealing with the high input cost and meat quality problems of Asian seabass reared in freshwater earthen ponds, and possibly with their muddy-earthy flavour, is to co-culture them with Nile tilapia. This co-culture system results in greater fish yields and higher economic returns than a monoculture system (Pechsiri et al., 2018). Also, the co-culture system with tilapia would be considered one of the most effective ways to control the tilapia fry population, which will be consumed by the Asian seabass. However, the fillet quality of Asian seabass when co-cultured with Nile

tilapia is unclear, especially in freshwater earthen ponds.

This study analyses and determines the proximate composition, fatty acid profile, and chemical taste taint of the Asian seabass fillet from both monoculture and co-culture freshwater systems. The results of this study will provide an understanding of the nutritional level of Asian seabass fillets from the mono and co-cultured systems. The findings could be used as guidelines regarding the appropriate culture system to improve the fillet quality of Asian seabass for human consumption.

Materials and Methods

Ethics statement

All the methods and experimental protocols of this study were performed following the guidelines and regulations approved by the animal ethics committee of Thaksin University (approval number ID #2559A10502019).

Experimental fish and design

The experiment was conducted using a completely randomised design in nine, 30 m^2 earthen ponds from April 2016 to September 2016 at Thaksin University, Thailand. Three culture systems were designed, including one monoculture system and two co-culture systems with Nile tilapia (Table 1). The monoculture system (T1) was stocked with Asian seabass *Lates calcarifer* (Bloch, 1790) while the co-culture system (T2 and T3) was with the addition of Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758). There were two steps involved in the preparation of the fish for the co-culture experimental system: 1) After pond preparation, eighteen female and six male Nile tilapias (150 to 160 g) were stocked in each pond of the six ponds; three ponds for treatment T2 and three ponds treatment T3. 2) Meanwhile, Asian seabass fingerlings of 12 cm total length and 38 g weight were acclimatised in freshwater for one week and then 30 fish were stocked into each of the nine experimental ponds. Two months after the stocking of adult tilapia, the recruitment of their fingerlings was seen in T2 and T3 and were eaten by the Asian seabass. There was no freshwater supply into the pond and no water exchange throughout the experimental period, and no aeration was provided. Water quality, including dissolved oxygen (DO), pH, phosphorus, total ammonia, alkalinity, and transparency were measured monthly according to the methods of APHA (1995).

During the six-month culture period, commercial diet (Thai Union Feedmill Co., Ltd., Thailand) was provided to the fish as per the experimental design (Table 1). Two diets, i) floating commercial marine fish feed and ii) floating commercial catfish feed of 5 mm pellets, were used in the monoculture and co-culture systems, respectively. Fish in T1 and T3 system were fed daily, and in T2 system the fish were fed every other day. Fish were fed twice until apparent satiation. The proximate composition for the marine fish feed was 43.32 % protein, 12.73 % fat, and 6.10 % moisture, and the fatty acid profile was 11.39 % of total n-3 fatty acids and 12.06 % of total n-6 fatty acids. Pongsri et al. (2015) reported that the proximate composition of commercial catfish feed was 30.19 % protein, 8.30 % fat, 7.49 % ash, and 10.08 % moisture. Nile tilapia fingerlings have 11 % protein wet weight, 3–4 % fat, and 3–4 % ash (Sultana et al., 2012). All Asian seabass were harvested after six months of culture.

Sample collection and preparation of fish samples

At the end of the experiment, five fish from each pond with an average mean weight between 350–400 g were selected. These fish were slaughtered and then filleted. The ventral and dorsal tissues were separated. Samples from the replicate of each treatment were pooled and then cut into small pieces for analysis.

Fish fillet quality analysis

Fish fillet quality was evaluated in terms of proximate composition, fatty acid composition, and chemical taste taint. The proximate analysis of the samples for moisture, crude protein, fat, and ash contents were determined using methods described by the Association of Official Analytical Chemists (2000). The samples were dried in an oven at 105 °C until constant weight to determine the moisture content, and the ash content was determined using a muffle furnace for 7 h at 550 °C. Total nitrogen (N) was found using the Kjeldahl method (Kjeltech auto analyser, VAP 300, Gerhardt), and the crude protein value was determined by multiplying N by 6.25. The crude fat was determined by using a Soxhlet apparatus with petroleum ether.

Lipids were extracted according to the method described by Olive et al. (2009). Approximately 1–1.5 g of each ventral and dorsal frozen tissue sample was homogenised in 10–15 mL of chloroform:methanol (2:1, V/V). A known quantity of nonadecanoic acid (C19:0) supplied by Sigma was used as an internal standard. The fatty acid composition was determined by converting the lipids into fatty acid methyl esters (FAMEs) (Olive et al., 2009). The FAMEs were then separated and analysed by capillary gas chromatography-flame ionisation detection (GC-FID) (Agilent Technologies 6890N) equipped with a DB-23 J & W column (30 m × 0.25 mm internal diameter, 0.25 µm film thickness). Hydrogen was used as the carrier gas, giving a flow rate of approximately 2 $mL.min^{-1}$. For optimum separation, the temperature profile was programmed at 60 °C for 1 min and then increased at 20 $°C.min^{-1}$ to 140 °C, held for 3 min, then increased at

Table 1. Experimental design of using Asian seabass *Lates calcarifer* for monoculture, and co-culture systems with Nile tilapia *Oreochromis niloticus*.

Culture systems	Number of Asian seabass	Number of tilapia	Type of feed	Feeding regimes
Mono-culture T1	30	-	Marine fish feed	Daily
Co-culture T2	30	24 (18 F:6 M)	Catfish feed	2 days interval
Co-culture T3	30	24 (18 F:6 M)	Catfish feed	Daily

M: male; F: female

10 °C.min^{-1} to 190 °C, held for 3 min, and then increased at 10 °C.min^{-1} to 220 °C and held for 8 min. The retention time of the individual peaks was identified and compared to the external standards: Supelco FAME mix GLC-100 and Supelco 37 component FAME mix. Quantification of each fatty acid was determined by comparing each individual peak area to that of the internal standard of known concentration and expressed as mg.g^{-1} dry weight (DW) of the fish tissue sample.

Chemical taste taint in the fish fillet was quantified by analysing the levels of geosmin (GSM) and 2-methyl-isoborneol (2-MIB), using headspace solid-phase micro-extraction (HS-SPME), followed by gas chromatography-mass spectrometry (GC/MS) as described by Grimm et al. (2004). Five grams of minced fillets and 10 mL of methanol were placed into a 20 mL straight-sided vial. Sodium chloride (1.9 g) was also added to the vial, which was then securely sealed with a crimp cap, fitted with a Viton septum (Supelco), and placed in a CTC SPME autosampler (Leap Technologies, USA). The sample was then heated to 65 °C on a hotplate stirrer and exposed to the SPME fibre for a 12 min adsorption period while undergoing vigorous agitation. After 12 min, the fibre was withdrawn from the sample and desorbed under a splitless mode at 230 °C for 5 min in the injection port of an HP 6890 N Network gas chromatograph, equipped with a 5973 mass selective detector (Agilent Technologies, USA), operated in scanning mode. For qualitative analysis, the oven was held at 60 °C for 1 min, then temperature programmed at 15 °C.min^{-1} to 220 °C and maintained for 8 min. Geosmin and 2-MIB levels in the fillets were determined by using a linear internal standard method.

Statistical analysis

Data were analysed using SPSS (version 16.0) software package to assess the level of significance at the 5 % level. Analysis of variance (ANOVA) was performed with the parameters and to compare the treatments Duncan's multiple range test was used.

Results

Water quality

During the experimental period, DO, pH and phosphorus varied from 2–4.5 mg.L^{-1}, 6.4– 7.6, and 0.001–0.0132 mg.L^{-1}, respectively, in all treatments. Before the end of the experiment (4–6 months), the amount of phosphorus was significantly higher in the monoculture ponds (0.0132 mg.L^{-1}) than in the co-culture ponds (0.0017 mg.L^{-1}). Total ammonia was significantly higher in T1 (0.54–1.25 mg.L^{-1}) and T3 (0.30–0.94 mg.L^{-1}) ponds than that of T2 (0.16–0.75 mg.L^{-1}) ponds. The alkalinity was significantly higher in T2 than that of the T1 and T3. In the first 1–2 months, it was 130–150 mg.L^{-1}, but at the end of the experiment, it decreased to approximately 90 mg.L^{-1}. Transparency was significantly higher in the T2 and T3 ponds (14–23.7 cm) than in the T1 ponds (4.3–11.5 cm).

Proximate composition of the fillet

The proximate compositions of Asian seabass fillets from different culture systems are shown in Table 2. The study found a significant difference ($P < 0.05$) in proximate fillet composition among the three rearing systems. A significantly higher percentage of crude protein (80.8 ± 0.3 %) and the lowest percentage of crude fat contents (5.2 ± 0.1%) were observed in Asian seabass from the T2 co-culture system. On the contrary, Asian seabass from the T3 co-culture systems recorded the highest crude fat content (10.2 ± 0.2 %) and lowest crude protein content (75.8 ± 0.1 %). Asian seabass from the monoculture system (T1) had crude protein (78.9 ± 0.4 %) and crude fat (6.9 ± 0.1 %) content values in between T2 and T3. There was no significant difference in the moisture and ash content among the treatments. The moisture and ash content ranged between 78.0–78.8 % and 5.5–6.0 %, respectively.

Fatty acid composition

The fatty acid composition is listed in Table 3. There was a significant difference ($P < 0.05$) in the overall amount of fatty acid in the fillets between the ventral and dorsal areas and among treatments. Ventral fillets of Asian seabass from the T1 and T3 systems contained significantly higher amounts of total fatty acid than dorsal fillets. Conversely, Asian seabass from the T2 system had significantly higher total fatty acid content in the dorsal fillet compared to the ventral fillet. The fillets from T1 demonstrated a significantly higher level of total fatty acid than the fillets from T2 and T3. The highest level of total fatty acid (103.82 ± 28.63 mg.g^{-1} DW) was recorded in the ventral fillets from T1. Both T2 and T3 had low total lipid contents, ranging from 6.11 ± 1.2–39.09 ± 21.28 mg.g^{-1} DW.

Table 2. Fillet proximate composition (per cent dry weight) of Asian seabass *Lates calcarifer* grown in monoculture and co-culture systems with Nile tilapia *Oreochromis niloticus* in freshwater earthen-ponds.

Culture systems	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Mono-culture and fed daily with marine fish feed (T1)	78.0 ± 0.6[a]	78.9 ± 0.4[b]	6.9 ± 0.1[b]	6.0 ± 0.6[a]
Co-culture and fed at a 2 day interval with catfish feed (T2)	78.8 ± 0.5[a]	80.8 ± 0.3[a]	5.2 ± 0.1[c]	5.5 ± 0.5[a]
Co-culture and fed daily with catfish feed (T3)	78.4 ± 0.2[a]	75.8 ± 0.1[c]	10.2 ± 0.2[a]	5.9 ± 0.3[a]

Data are presented as means ± SD and values in the same column with different letters are significantly different ($P < 0.05$).

Seventeen fatty acids, including five saturated fatty acids (SFAs), three monounsaturated fatty acids (MUFAs), and nine polyunsaturated fatty acids (PUFAs) were identified. In terms of the fatty acid content of all samples, there were 9.83–63.62 % of PUFAs, 22.87– 36.20 % of SFAs and 10.56–17.99 % of MUFAs.

For SFAs, the content range was 1.58 ± 0.17–37.10 ± 10.24 mg.g^{-1} DW. The highest value of 37.10 ± 10.24 mg.g^{-1} DW was obtained from the ventral fillets of T1, and a total of five SFAs found. Only two SFAs, C15:0 and C16:0, were found in the fish from T2 and T3. The SFAs level of T2 and T3 fish were 1.58 ± 0.17–3.51 ± 1.95 mg.g^{-1} DW and 4.84 ± 2.73–10.41 ± 6.39 mg.g^{-1} DW, respectively. The major SFAs in all specimens was Palmitic acid (C16:0), with levels reaching 25.81 ± 8.31 mg.g^{-1} DW in the ventral fillets from T1.

The MUFAs included oleic acid (C18:1 n-9c), elaidic acid (C18:1 n-9t), and heptadecenoic acid (C17:1 n-7) (Table 3). The content range of MUFAs was 1.04 ± 0.07–15.01 ± 4.18 mg.g^{-1} DW (10.56–17.99 %). Oleic acid (C18:1 n-9c) was a major MUFAs in T2 and T3 fish, while heptadecenoic acid (C17:1 n-7) was the predominant MUFA in the ventral fillets of T1 fish at 7.98 ± 2.32 mg.g^{-1} DW. Elaidic acid (C18:1 n-9t) was found in T1 fish, but not detected in T2 and T3 fish (Table 3).

All experimental fish demonstrated high PUFAs content, ranging from 3.49 ± 1.12 mg.g^{-1} DW in the ventral fillets of T2 to 51.71 ± 14.21 mg.g^{-1} DW in the ventral fillets of T1 (Table 3). A total of nine fatty acids, including five n-6 PUFAs and four n-3 fatty acids, were identified and determined in the T1 fillets. Only five fatty acids with two n-6 fatty acids and three n-3 fatty acids were identified in the T2 fillets. In T3 fillets, three n-6 fatty acids and two n-3 fatty acids were identified.

The fillets of T1 and T3 had a significantly higher level of n-6 fatty acids (8.51 ± 5.97–37.41 ± 3.40 mg.g^{-1} DW) than n-3 fatty acids (1.82 ± 0.14–14.31 ± 10.81 mg.g^{-1} DW). The total n-3 fatty acids levels of both the ventral and dorsal fillets of T2 fish were 1.82 ± 0.14 and 5.15 ± 2.45 mg.g^{-1} DW, respectively and the levels of total n-6 fatty acids were 1.68 ± 1.25 and 4.30 ± .2 18 mg.g^{-1} DW, respectively. Linoleic acid (C18:2 n-6) was the most abundant n-6 fatty acid (24.99 ± 7.28 mg.g^{-1} DW), and γ-linolenic (C18:3 n-6) was the second most abundant (0.56 ± 0.43–8.64 ± 2.34 mg.g^{-1} DW) of the lipids in all experimental fish. Arachidonic acid (C20:4 n-6) was only found in the dorsal fillets of T1, and only in small amounts (0.40 ± 0.57 mg.g^{-1} DW).

The content range of docosahexaenoic acid (C22:6 n-3, DHA) and eicosapentaenoic acid (C20:5 n-3, EPA) were 0.86 ± 0.09–8.37 ± 2.01 mg.g^{-1} DW and 0.00 ± 0.00–1.00 ± 1.41 mg.g^{-1} DW, respectively. They were significantly different ($P < 0.05$) in the different culture systems with the greatest value of DHA (8.37 ± 2.01 mg.g^{-1} DW) in the ventral fillets of T1 and the lowest value (0.86 ± 0.09 mg.g^{-1} DW) in the ventral fillets of T2. The opposite was found for EPA. The highest value of EPA (1.00 mg.g^{-1} DW) was significantly different in the dorsal fillets of T2 compared to 0.23 ± 0.33 mg.g^{-1} DW of EPA in the dorsal fillets of T1. Moreover, there was an absence of EPA in T3 and in the ventral fillets of T1 and T2. The n-3/n-6 fatty acid ratio obtained in this investigation was 0.38 and 0.52, 1.09 and 1.20, 0.13 and 0.30 in ventral and dorsal fillets of T1, T2, and T3 fish, respectively.

Chemical taste taint

Two muddy-taint compounds, geosmin, and 2-methyl-iso-borneol (2-MIB) were evaluated. Geosmin was not detected in the T2 fillets. Geosmin in T1 fillets (0.0113 ± 0.0075 µg.kg^{-1}) was significantly higher than T2 fillets but not T3 fillets (0.0103 ± 0.0015 µg.kg^{-1}). The fillets from T1 fish had the highest 2-MIB concentration (0.0227 ± 0.0025 µg.kg^{-1}). This was significantly higher than T2 (0.0120 ± 0.0020 µg.kg^{-1} and T3 fillets (0.0103 ± 0.0015 µg.kg^{-1}.

Discussion

The results of this study agree with those of Krishna et al. (2018), who reported that changes in the chemical composition of the fish body reflect the storage or depletion of energy reserves. The Asian seabass in the T2 and T3 systems were fed with low protein feed but could also prey on tilapia fry. The fillets of T2 fish had the highest protein (80.8 ± 0.3 %) and the lowest fat (5.5 ± 0.5 %) contents. The higher protein content of T2 fish in this study could be due to the reversed condition of protein retention in the muscle, which can occur with low protein feeds (Syahailatua et al., 2017). Conversely, T3 fish were observed to have the lowest protein and the highest

Table 3. Fatty acid composition (mg.g^{-1} DW) in ventral and dorsal fillets of Asian seabass *Lates calcarifer* grown in monoculture and co-culture systems with Nile tilapia *Oreochromis niloticus* in freshwater earthen-ponds.

Fatty acids	Mono-culture fed daily with marine fish feed (T1)		Co-culture fed 2-day interval with catfish feed (T2)		Co-culture fed daily with catfish feed (T3)	
	Ventral fillet	Dorsal fillet	Ventral fillet	Dorsal fillet	Ventral fillet	Dorsal fillet
C15:0	5.34 ± 1.46	2.82 ± 2.04	0.00 ± 0.00	0.25 ± 0.36	1.03 ± 1.00	0.36 ± 0.51
C16:0	25.81 ± 8.31	14.77 ±12.09	1.58± 0.21	3.26± 1.95	9.38 ± 6.62	4.48 ± 2.72
C18:0	0.80 ± 0.57	0.39 ± 0.56	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C21:0	1.60 ± 0.45	0.59 ± 0.83	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C23:0	3.56 ± 0.98	1.92 ± 1.49	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Total SFA	37.10 ±10.24^{a} (35.74 %)	20.49 ± 14.78^{b} (36.20 %)	1.58 ± 0.17^{e} (26.42 %)	3.51 ± 1.95^{d} (22.87 %)	10.41 ± 6.39^{c} (25.82 %)	4.84 ± 2.73^{d} (26.90 %)
C17:1 n-7	7.98 ± 2.32	1.63 ± 0.74	0.00 ± 0.00	0.39 ± 0.56	1.01 ± 0.99	0.25 ± 0.36
C18:1 n-9t	0.95 ± 0.67	0.43 ± 0.61	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C18:1n-9c	6.08 ± 1.19	1.53 ± 1.11	1.04 ± 0.07	1.74 ± 0.49	3.11 ± 1.33	1.84 ± 0.56
Total MUFA	15.01 ± 4.18^{a} (14.44 %)	3.59 ± 1.28^{b} (10.84 %)	1.04 ± 0.07^{d} (17.99 %)	2.13 ± 1.92^{c} (14.25 %)	4.12 ± 2.30^{b} (10.56 %)	2.09 ± 0.91^{c} (14.40%)
C18:2 n-6	24.99 ± 7.28	16. 97±12.22	1.11 ± 0.82	3.15 ± 1.61	12.34 ± 7.54	5.26 ± 3.11
C18:3 n-3	3.98 ± 1.12	1.68 ± 1.75	0.00 ± 0.00	0.00 ± 0.00	0.61 ± 0.86	0.00 ± 0.00
C18:3 n-6	8.64 ± 2.34	3.81 ± 4.14	0.56 ± 0.43	1.14 ± 0.57	9.46 ± 5.45	3.26 ± 2.92
C20:2 n-6	1.82 ± 0.49	0.87 ± 0.83	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C20:3 n-3	1.96 ± 0.41	1.27 ± 0.63	0.95 ± 0.05	1.51 ± 0.23	1.17 ± 0.21	0.92 ± 0.05
C20:4 n-6	0.00 ± 0.00	0.40 ± 0.57	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C20:5 n-3	0.00 ± 0.00	0.23 ± 0.33	0.00 ± 0.00	1.00 ± 1.41	0.00 ± 0.00	0.00 ± 0.00
C22:2 n-6	1.95 ± 0.59	0.78 ± 1.10	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C22:6 n-3	8.37 ± 2.01	5.22 ± 3.20	0.86 ± 0.09	2.65 ± 0.95	0.98 ± 0.70	1.60 ± 0.11
Total PUFA	51.71 ± 14.21^{a} (49.81 %)	31.23 ± 24.56^{b} (52.96 %)	3.49 ± 1.12^{d} (55.59 %)	9.45 ± 4.61^{c} (62.88 %)	24.56 ± 13.29^{b} (63.62 %)	11.04 ± 6.06^{c} (60.71 %)
Total	103.82 ± 28.63^{a}	55.31 ± 38.27^{a}	6.11 ± 1.2^{c}	15.09 ± 7.57^{b}	39.09 ± 21.28^{b}	17.97 ± 9.66^{b}
Total n-9	7.03 ± 1.86^{a}	1.96 ± 0.54^{c}	1.04 ± 0.07^{d}	1.74 ± 0.49^{c}	3.11 ± 1.33^{b}	1.84 ± 0.56^{c}
Total n-7	7.98 ± 2.32^{a}	1.63 ± 0.74^{b}	0.00 ± 0.00^{d}	0.39 ± 0.56^{c}	1.01 ± 0.99^{b}	0.25 ± 0.36^{c}
Total n-6	37.41 ± 3.40^{a} (35.90 %)	20.57 ± 6.54^{b} (28.52 %)	1.68 ± 1.25^{e} (24.09 %)	4.30 ± 2.18^{d} (28.47 %)	21.80 ± 12.9^{b} (54.69 %)	8.51 ± 5.97^{c} (42.85 %)
Total n-3	14.31 ± 10.81^{a} (13.93 %)	10.67 ± 18.10^{a} (24.44 %)	1.82 ± 0.14^{d} (31.50 %)	5.15 ± 2.45^{b} (34.41 %)	2.76 ± 0.42^{c} (8.93%)	2.53 ± 0.15^{c} (17.86%)
Σn3 / Σn6	0.38	0.52	1.09	1.20	0.13	0.30

Data are presented as means ± SD and values in the same row with different letters are significantly different ($P < 0.05$).

fat contents, which was probably due to their daily feed and their access to Nile tilapia fry. Excess energy relative to protein content in the diet can result in high lipid deposition (Craig, 2017). Similar trends of increased fat deposition have been reported in fish, which are fed bait-fish (Glencross et al., 2008).

Fatty acids were found to be more pronounced in ventral than in dorsal fillets for T1 and T3 fish. Similarly, Percival et al. (2008) showed that farmed Asian seabass showed a strong localisation of body lipid, with the highest levels (~ 30 %) occurring in the belly area. Their levels were also above the range observed in wild-caught Asian seabass muscle (0.67 g·100 g^{-1} FW) (Ho and Paul, 2009). In contrast, T2 fish had a higher amount of fatty acid in the dorsal compared to the ventral fillets. This may be due to the maintenance of lipid homeostasis, where fatty acids are preserved in the dorsal region during feed deprivation (Cleveland et al., 2018).

The fatty acid composition of all samples was characterised by high contents of polyunsaturated fatty acid (PUFA) (49.83–63.62 %), low saturated fatty acid (SFA) (22.87–36.20 %), and low monounsaturated fatty acid (MUFA) (10.56–17.99 %). These characters were also observed in the fillets of Asian seabass cultured in brackish water (Mohd-Yusof et al., 2010) and wild-caught Asian seabass in Myanmar (Ho and Paul, 2009). These results are different from those for farmed Asian seabass in Vietnam and Australia, in which the levels of total SFA were higher than PUFA. Plaipetch et al. (2008) also found high levels of SFA (63.76 %) in farmed Asian seabass in Thailand. The high level of SFA may be due to the different geographical origins and dietary intake, which are considered as significant factors that influence the fatty acid composition of fish (Ngoh et al., 2015).

The fillets of T1 fish had higher levels of SFA, MUFA, and PUFA when compared to the fillets of T2 and T3 fish. The fatty acid levels in T1 fish could be attributed to the fact that the fillet portions contain higher amounts of total fatty acid than T2 and T3 fish. The level of SFA observed in the ventral (37.11 mg.g^{-1} DW or 0.816 g.100 g^{-1} FW) and dorsal (20.49 mg.g^{-1} DW or 0.451 g.100 g^{-1} FW) fillets of T1 fish were similar to the mean value for the SFA (0.77 ± 0.51 g.100 g^{-1} FW) of this species reared in brackish pond water and fed commercial marine fish feed (Plaipetch et al., 2008). Palmitic acid (C16:0) was the dominating SFA in all the specimens, which is a common characteristic of freshwater fish (Chauke et al., 2008). It is also common in wild-caught Asian seabass (Ho and Paul, 2009) and Asian seabass fed pelleted feeds (Ngoh et al., 2015). Heptadecenoic acid (C17:1 n-7) was the predominant MUFA in T1 fish with 1.63 ± 0.74–7.98 ± 2.32 mg.g^{-1} DW or 0.036–0.176 mg.100 g^{-1} FW. These levels are lower than the levels observed in some freshwater fish such as Moonfish *Trachinotus blochii* (Lacépède, 1801) (81.5 mg.100 g^{-1} FW) (Aziz et al., 2013). Oleic acid (C18:1 n-9c) was the most prevalent MUFA in T2 and T3 fish. This result is like those found in the studies carried out in wild-caught Asian seabass (Ho and Paul, 2009). However, the levels of oleic acid (C18:1 n-9c) were lower in the T2 and T3 fish than in the T1 fish. According to Ackman (1989), oleic acid (C18:1 n-9c) has an exogenous origin and usually reflects the diet of the fish.

Elaidic acid (C18:1 n-9t) was found in T1 fish but was not detected in T2 and T3 fish (Table 3). The absence of elaidic acid in T1 could be due to the large percentage of fat in T1 fish as indicated by Mohamed (2013), who found that elaidic acid (C18:1 n-9t) was the most abundant MUFA in the fat tissues of *Clarias gariepinus* ((*Clarias lazera* (Burchell, 1822)) but was not detected in *Labeo niloticus* (Linnaeus, 1758). There were higher levels of total n-3 fatty acids than total n-6 fatty acids in the fillets of T2 fish, which is similar to that recorded in marine fish (Li et al., 2011). Moreover, the highest value of EPA (1.00 mg.g^{-1} DW or 0.21 mg.g^{-1} FW) was found in the dorsal fillets of T2 fish. This value was higher than those of the EPA (0.0155 mg.g^{-1} FW) in wild-caught Asian seabass of Myanmar, as reported by Ho and Paul (2009).

The high levels of EPA and n-3 fatty acids resulted in higher values of the n-3:n-6 ratios for both ventral and dorsal fillets of T2 fish (1.09 and 1.20) compared to those in T1 (0.38 and 0.52) and T3 fish (0.13 and 0.30). This ratio was also higher than marine cultured Asian seabass (0.58) (Plaipetch et al., 2008). It has been suggested that this ratio is a useful indicator for comparing the relative nutritional value of fish oils (Osman et al., 2001). A ratio of 1:1–1:5 would be healthy to include in the human diet. This means that T2 fish have a higher nutritional value compared to T1 and T3 fish. Therefore, consumers could enjoy the health benefits associated with food rich in n-3 fatty acids, including reduced symptoms of depression and improved cardiovascular health (Craig, 2017).

Furthermore, the tainting of fish fillet by geosmin was not detected in T2 fish. There were low geosmin content in T2 and T3 fillets because of low total fatty acid concentration in their fillets. The lower geosmin could also be due to the filtering of microalgae by tilapia in these ponds. A similar result was obtained by Torrans and Lowell (1987) in the case of a tilapia-catfish polyculture, which demonstrated that the reduction of microalgae eaten by blue tilapia *Oreochromis aureus* (Steindachner, 1864) led to the off-flavour in channel catfish *Ictalurus punctatus* (Rafinesque, 1818). However, the concentration of geosmin and 2-MIB in the fillets of all treatments in this study was lower than the geosmin concentration (0.74 to 4.47 µg.kg^{-1} wet weight) in Asian seabass from freshwater cages in tropical Australia (Jones et al., 2013).

Conclusion

The fillet quality in terms of nutritional value and chemical taste taint was affected by different rearing systems. The results of this study suggested that the fillets of Asian seabass from co-culture systems with Nile tilapia fed every other day with commercial catfish feed could yield quality fillet with a good source of protein (80.8 % DW), n-3 fatty acids, especially EPA (1.00 mg.g^{-1} DW), low in fat (5.2 % DW)

and low in chemical taste taint (0.0120 µg.kg^{-1} 2-methyl-isoborneol) as well as an absence of geosmin.

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