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Seasonal variations in proximate and fatty acid composition of sobaity sea bream (*Sparidentex hasta*) in Kuwait waters

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Original Article

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Abstract

The objective of the study was to investigate the seasonal variations in proximate and fatty acid composition of wild sobaity (*Sparidentex hasta*) for a one-year period during (i) pre-spawning (October–December), (ii) spawning (January–March), (iii) post-spawning (April–June) and summer (July–September). Five male and five female fish were collected from market each month and used for the study. Skinless fillets from both sides of sobaity were taken, chopped, minced, frozen and freeze dried. Freeze-dried ground male and female fish samples were pooled separately and homogenized for proximate composition and fatty acid analysis. The results of the investigation showed that the muscle proximate composition and fatty acid profile of sobaity differed significantly ($P < 0.05$) among different seasons with the highest muscle lipid during the pre-spawning and spawning season. Palmitic acid (C16:0) was the most dominant muscle fatty acid followed by oleic acid (C18:1n-9). The muscle docosahexaenoic acid (DHA, C22:6n-3) levels in pre-spawning and spawning seasons were significantly ($P < 0.05$) higher than those in other seasons. A good n-3/n-6 ratio (2.26–3.11) and the higher DHA levels (10.16–11.47%) observed in muscles during the pre-spawning and spawning season indicated a better nutritional value of sobaity at this time of the year.

Introduction

Fish provides a number of fatty acids (FAs) with valuable roles in human health. The nutritional significance of fish consumption is closely related to the n-3 polyunsaturated fatty acids (PUFA), in particular eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The consumption of fish and fish oils seems to decrease the risk of coronary heart disease (Kris-Etherton *et al*., 2002). Recently, there has been a growing interest in the medical and public health communities about the role of highly unsaturated n-3 PUFAs in human health. The health benefits of n-3 PUFA may include the possible reduction of a number of disorders, such as coronary heart disease, inflammation, hypotriglyceridaemic effect, allergies, hypertension, arthritis and autoimmune disorders (Mozaffarian *et al*., 2005; Mnari *et al*., 2007; Delgado-Lista *et al*., 2012).

The quality and nutritional composition of fish are not only associated with type of fish species, but also depend on the nutritional composition of food, habitat, temperature, seasonality, environmental condition, age and sex (Ackman, 1989). The season can be important because it can affect the composition of diets. Differences in the chemical composition of fish are closely associated with feed intake, migratory swimming and sexual maturation in connection with spawning (Tzikas *et al*., 2007). Thus, to establish the nutritional value as well as eating quality of fish in different seasons of the year, it is important to determine the seasonal variations in biochemical composition of fish.

The sobaity sea bream (*Sparidentex hasta* Valenciennes 1830) is relatively widespread in the Arabian Gulf and eastward to the coast of India.It has been considered a desirable fish for consumption for over a century (Kitto, 2004). The Aquaculture Program of the Kuwait Institute for Scientific Research (KISR), Kuwait has succeeded in developing various technologies related to culture of sobaity bream in tanks and cages (Teng *et al*., 1987; Hossain *et al*., 2017). Hossain *et al*. (2017) reported higher content of n-3 PUFA in wild sobaity than in cultured sobaity. However, those researchers evaluated the FA only in one season of the year, pre-spawning. In the other seasons of the year wild sobaity bream and gilthead bream contain less fat compared with cultured fish (Orban *et al*., 2003; Mnari *et al*., 2007; Hossain *et al*., 2012). No reports are available in the literature on the influence of seasonal variations on the biochemical composition of sobaity bream. Thus, this work aimed at investigating seasonal variations in proximate and fatty acid composition of wild sobaity for a one-year period during (i) pre-spawning (October–December), (ii) spawning (January–March), (iii) post-spawning (April–June) and summer (July–September).

Materials and methods

To investigate the seasonal variations of biochemical composition between male and female fish, monthly samplings of wild sobaity sea bream (*S. hasta*) were carried out during the months from October 2015 to September 2016 from the Sharq fish market, Kuwait. Marketable sobaity in the size range of 600–900 g were collected from the Sharq fish market and were brought into the Fish Nutrition Laboratory of the Marine Research Station, Salmiya, covered in ice. Fish were measured for their standard lengths (cm) and weight (g). For calculation of gonado-somatic index (GSI), viscero-somatic index (VSI), hepato-somatic index (HSI) and condition factor (CF) fish were dissected and their gonad, viscera and liver were removed carefully and weighed. Five male and five female fish were identified and selected each month for the study. Skinless fillets from both sides of sobaity were taken, chopped, minced and frozen. Frozen samples were dried using a freeze dryer and then finely ground using a grinder mixer (Preeti, Model MG 139, India). Freeze-dried ground male and female fish samples were pooled separately and homogenized for fatty acid analysis.

The fish samples were analysed in triplicate for proximate composition according to the standard procedure (AOAC, 2000). For FA analysis the lipid contents of samples were extracted by the Bligh & Dyer (1959) method. FA methyl ester standard mixtures comprising 25 different fatty acids (ranging from C8 to C22:6) were obtained from Altech Associates, Deerfield, MA, USA. Transesterification of fat in samples was done according to Hartman & Logo (1973) with slight modification by using methanolic KOH (0.1 M) to change all fatty acids into methyl ester form. The FA composition was determined by gas chromatography (AOCS, 1992) after preparing methyl esters and analysing them by an HP 6890 gas chromatograph (Hewlett-Packard, Palo Alto, CA, USA) equipped with a chromapack column (CP-Sil 88 50 meter, ID 0.25 mm, Varian Inc, Palo Alto, CA, USA). The oven temperature programme was as follows: initial temperature set at 50°C, with an increment of 10°C every minute reaching a final temperature of 235°C, held for 7 min. The FAs were identified by comparing their retention times with a mixture of standards containing all of the FAs. Each FA was quantified by calculating its peak area relative to the total peak area. The results are reported as a percentage of total FAs. Additionally, whenever necessary the percentage of individual FA content was calculated in absolute value (i.e. g FA/100 g fish muscle) by taking into consideration the fat content in fish muscle as follows:

$$\text{\% individual FA in the sample (absolute)} = \frac{\text{\% fatty acid} \times \text{\% fat in the sample}}{100}$$

Among the FAs total monounsaturated fatty acids (MUFA), total saturated fatty acids (SFA), total polyunsaturated fatty acids (PUFA) and n-3/n-6 ratios in muscles were calculated and used for statistical analysis.

In the Arabian Gulf, the spawning season for sobaity is considered to be between January and March. For better explanation of results, the one-year sampling period (October 2015 to September 2016) was divided into four periods: pre-spawning (October–December), spawning (January–March), post-spawning (April–June) and summer (July–September).

The data were tested for statistical significance using one-way and two-way ANOVA (Duncan, 1955) to see the effects of sex, season and their interactions between treatment means. Where significant differences ($P < 0.05$) were detected Tukey's test was used to rank the group. Statistical analyses were carried out using Statistical Package for Social Sciences (SPSS, version 20.0).

Results and discussion

Table 1 shows the standard length, weight ranges and averages of fish used in the study of seasonal variations in nutritive value of wild sobaity. No significant ($P > 0.05$) differences were observed between the respective lengths and weights of male and female sobaity collected during different months of the year. The average standard lengths of male sobaity in different months ranged between 29.9 and 33.8 cm (mean 31.8 ± 1.4 cm); while it ranged between 30.1 and 33.5 cm (mean 31.5 ± 1.5 cm) for females. The monthly average weights of male sobaity ranged between 701.1 and 863.6 g with a mean value of 787.6 ± 5.2 g; while it ranged between 704.9 and 894.5 g with a mean weight of 781.1 ± 93.9 g for females. It is worth mentioning that attempts were made to collect fish from the fish market within the similar size ranges (600–900 g) each month.

The monthly ranges and averages of GSI, VSI, HSI and CF of male and female sobaity are presented in Table 2. The significantly ($P < 0.05$) highest average GSI of both male and female sobaity were observed in the spawning season and the lowest in the post-spawning season. As expected, in all seasons the GSI values of females were significantly higher than those of males (Table 2). Almatar *et al.* (2004) also found significantly higher GSI value in silver pomfret (*Pampus argenteus*) during the spawning season. No significant interactive effect ($P > 0.05$) of sex and season was observed on the GSI, VSI, HSI and CF of sobaity; but, the season did have a significant effect. The significantly ($P < 0.05$) highest VSI values were observed in both males and females in the pre-spawning season, while the VSI value was lowest in the post-spawning season. No significant ($P > 0.05$) differences were observed between the HSI values of males and females in different seasons. But, the HSI values of both males and females in the spawning season were significantly ($P < 0.05$) higher than those in other seasons. Although no significant ($P > 0.05$) differences were observed between the CF values of respective male and female sobaity in different seasons, the CF values of both males and females in spawning and summer seasons were significantly ($P < 0.05$) higher than those in other seasons. The better CF of sobaity in spawning season could be related to the availability of food, fat accumulation in the preceding season and enhancement during their gonadal development (Alhassan *et al.*, 2014). On the other hand, in the summer season in addition to common foods, the sobaity has access to plenty of juvenile mullets (*Liza macrolepsis*) available in the Arabian Gulf that are highly nutritious, which ultimately results in better CF for sobaity.

Table 3 shows the seasonal variations in muscle proximate composition of male and female sobaity. The proximate composition of wild sobaity varied significantly ($P < 0.05$) among different seasons. The muscle moisture content of sobaity varied with the seasons and was inversely related to the lipid content (Orban *et al.*, 2011). In the present study, the muscle protein content (18.3–19.9%) in sobaity was higher than those previously found in wild (17.62%) and cultured (16.25%) sobaity bream (Hossain *et al.*, 2012) but slightly lower than that of 20.2% in wild gilthead bream (Grigorakis, 2007). The comparatively lower muscle protein observed in sobaity throughout the pre-spawning season might be associated with the synchronized proteolysis of the protein to guarantee access to the essential amino acids for gonadal development for the spawning season (Martin *et al.*, 1993). In the present study, the muscle lipid (1.9–3.5%) level was lower than those observed in wild (4.60%) and cultured (4.14%) sobaity bream (Hossain *et al.*, 2012), but higher than that (1.4%) found in wild gilthead bream (Grigorakis, 2007).

The higher muscle lipid content observed in both males and females throughout the pre-spawning season could be related to

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Table 1. Length, weight ranges and averages (±SD, N = 5) of fish used

		Length (cm)		Weight (g)	
Months	Sex	Range	Average ± SD	Range	Average ± SD
October	Male	32.1–34.0	33.8 ± 0.8	820.7–896.0	863.6 ± 31.4
	Female	33.0–34.1	33.5 ± 0.4	888.0–899.1	894.5 ± 4.1
November	Male	32.0–33.1	32.6 ± 0.5	714.6–899.1	812.4 ± 2.0
	Female	31.0–33.5	32.1 ± 0.8	741.3–896.8	793.2 ± 72.5
December	Male	31.0–33.1	31.8 ± 0.8	677.6–809.2	747.2 ± 52.6
	Female	31.2–34.0	32.7 ± 1.1	752.1–898.9	841.6 ± 60.9
January	Male	31.0–34.1	32.6 ± 1.2	650.1–807.0	774.4 ± 0.8
	Female	29.0–33.3	30.7 ± 1.6	659.8–898.9	705.8 ± 0.9
February	Male	31.0–32.1	31.3 ± 1.2	685.1–849.6	725.5 ± 60.6
	Female	31.1–32.2	31.1 ± 0.8	696.4–790.5	732.8 ± 41.7
March	Male	31.1–32.0	31.3 ± 0.5	763.0–838.3	793.8 ± 33.2
	Female	30.0–2.2	30.9 ± 0.9	620.9–899.1	766.1 ± 136.6
April	Male	31.5–33.5	32.4 ± 0.8	812.3–897.4	858.7 ± 30.7
	Female	30.0–33.5	31.5 ± 1.6	620.9–898.5	754.4 ± 137.3
May	Male	30.0–31.5	30.5 ± 0.7	723.3–876.8	793.2 ± 66.2
	Female	29.5–33.5	30.5 ± 1.7	706.0–898.5	761.7 ± 71.5
June	Male	29.0–31.1	29.9 ± 0.7	620.0–802.7	701.1 ± 72.9
	Female	29.0–31.5	30.1 ± 1.1	675.1–765.0	735.9 ± 54.5
July	Male	28.5–32.5	30.5 ± 1.7	624.8–802.7	743.7 ± 76.8
	Female	29.0–32.1	30.4 ± 1.2	600.0–805.5	704.9 ± 90.8
August	Male	30.1–34.0	32.3 ± 1.5	658.4–898.0	804.7 ± 89.2
	Female	30.0–33.2	31.5 ± 0.8	724.4–895.0	811.3 ± 78.1
September	Male	30.0–32.4	31.3 ± 1.0	766.3–899.1	832.2 ± 63.7
	Female	32.0–34.3	33.2 ± 0.8	785.1–896.0	870.0 ± 48.2
Mean values	Male		31.8 ± 1.4		787.6 ± 5.2
	Female		31.5 ± 1.5		781.1 ± 93.9

No significant ($P > 0.05$) difference between the mean length and weight of male and female sobaity.

Table 2. Seasonal variations in GSI, VSI, HSI and condition factor of male and female sobaity between October 2015 and September 2016[a]

Season[b]	Sex	GSI	VSI	HSI	CF
Pre-spawning	Male	0.28 ± 0.17c	4.21 ± 0.74a	0.74 ± 0.46b	2.36 ± 0.17b
	Female	0.39 ± 0.28bc	4.41 ± 1.84a	0.88 ± 0.42b	2.39 ± 0.14b
Spawning	Male	1.23 ± 0.55a	3.75 ± 0.97b	1.12 ± 0.29a	2.66 ± 0.21a
	Female	1.43 ± 0.44a	3.80 ± 1.62b	1.21 ± 0.29a	2.60 ± 0.21a
Post-spawning	Male	0.13 ± 0.06d	2.85 ± 1.03c	0.64 ± 0.16b	2.33 ± 0.32b
	Female	0.27 ± 0.15c	3.03 ± 0.71c	0.77 ± 0.24b	2.42 ± 0.19b
Summer	Male	0.31 ± 0.17c	3.52 ± 0.77b	0.66 ± 0.10b	2.59 ± 0.19a
	Female	0.53 ± 0.38b	3.46 ± 0.68b	0.76 ± 0.14b	2.56 ± 0.18a
Two-way ANOVA (*P*-value)					
Sex (A)		$P < 0.05$	NS	NS	NS
Season (B)		$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$
A × B		NS	NS	NS	NS

[a]Values (mean ± SD, N = 15) in a column with same letters are not significantly different determined by Tukey's test ($P < 0.05$).
[b]Pre-spawning = (October–December), spawning = (January–March), post-spawning = (April–June) and summer = (July–September).
GSI, Gonado-somatic index; VSI, Viscero-somatic index; HSI, Hepato-somatic index; CF, Condition factor.

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Table 3. Variations in proximate composition of male and female sobaity between October 2015 and September 2016 (% fresh matter basis)[a]

Season[b]	Sex	Moisture	Crude protein	Lipid	Ash
Pre-spawning	Male	76.3 ± 0.8b	18.6 ± 0.5c	3.5 ± 0.6a	1.2 ± 0.1a
	Female	76.2 ± 1.0b	18.7 ± 0.4c	3.5 ± 0.9a	1.2 ± 0.1a
Spawning	Male	77.9 ± 0.6a	18.3 ± 0.4d	2.4 ± 0.3b	1.2 ± 0.1a
	Female	77.8 ± 0.6a	18.3 ± 0.3d	2.4 ± 0.4b	1.2 ± 0.1a
Post-spawning	Male	77.5 ± 0.7a	19.3 ± 06b	1.9 ± 0.5c	1.1 ± 0.1b
	Female	77.6 ± 1.1a	19.1 ± 0.7b	2.0 ± 0.5c	1.1 ± 0.1b
Summer	Male	76.7 ± 1.0b	19.8 ± 06a	2.0 ± 0.4c	1.1 ± 0.1b
	Female	76.8 ± 0.7b	19.9 ± 0.4a	1.9 ± 0.5c	1.1 ± 0.1b
Two-way ANOVA (*P*-value)					
Sex (A)		NS	NS	NS	NS
Season (B)		$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$
(A × B)		NS	NS	NS	NS

[a]Values (mean ± SD, N = 15) in a column with same letters are not significantly different determined by Tukey's test ($P < 0.05$).
[b]Pre-spawning = (October–December), spawning = (January–March), post-spawning = (April–June) and summer = (July–September).

the fact that fish use fat reserves during gonadal maturation and spawning, as well as in winter (Shearer, 1994). Besides, a number of factors, including species, season, age, feeding regime and environment of the ecosystem affect the nutrient composition of the fishes (Shearer, 1994; Orban *et al*., 2007).

Table 4 shows the FA composition (% of total fatty acids) of the wild sobaity (male and female combined) in different seasons. In the present study, palmitic acid (PA, C16:0) was the major SFA followed by oleic acid (OA, C18:1n-9) which accounted for 23–28% and 16–22% of total FAs, respectively. Muscle OA can be food derived and also the saturated stearic acid (SA, C18:0) synthesized by FA synthetase can be desaturated initially by stearoyl CoA desaturase to form OA (Leaver *et al*., 2008). Saturated C16:0 and C18:0 FAs can be desaturated initially by steroyl CoA desaturase to form C16:1n-7 and C18:1n-9. These monosaturates may be further desaturated and elongated by specific fatty acyl desaturases and elongases, especially under conditions of essential fatty acid deficiency (Leaver *et al*., 2008). Muscle PA of sobaity throughout post-spawning and summer seasons was significantly ($P < 0.05$) higher than those in other seasons. Similar higher muscle PA was observed in wild white sea bream (Cejas *et al*., 2004), sea bass (Fuentes *et al*., 2010) and sobaity bream (Hossain *et al*., 2012). Muscle linoleic acid (LA, C18:2n-6) content (1.5–2.15%) did not vary among different seasons and these values are similar to that of 1.5% reported for wild sea bream (Hossain *et al*., 2012) but lower than that of 2.73% for wild sea bass (Fuentes *et al*., 2010) and 3.34% for white sea bream (Cejas *et al*., 2004).

The differences in muscle FA contents of sobaity bream in the present study could be due to the variations in food availability. In wild, sobaity bream have been observed to feed by grazing for prey on rocky surfaces, consuming a variety of prey, with crustaceans, polychaetes, teleosts and echinoderms as the major dietary group. The prey consumed also varies with fish size: juvenile fish feed on zooplankton (soft-bodied animals such as polychaete larvae, calanid larvae and other small crustaceans) and even on zoobenthos; bigger fish also consume benthic plants and animals (barnacles, bivalves, polychaetes, amphipods and other finfish). These might explain the higher levels of n-3 PUFA in sobaity muscles. In the Arabian Gulf during the summer season, sobaity bream intensely prey on abundant juvenile mullets (*L. macrolepsis*), which might also resulted in the higher muscle lipid and FA deposition in the pre-spawning and spawning seasons.

In general, the cultured fish show a tendency of having a higher LA than the wild counterpart (Alasalvar *et al*., 2002.) Plant oil used in fish feed contains a high proportion of LA which is accumulated in cultured fish largely unchanged since the marine fish has a low capacity for chain elongation and desaturation (Yamada *et al*., 1980). However, the presence of low levels of LA in wild sobaity is very important from the human health perspective, as consumption of wild sobaity will lead to an intake of fish with a better n-3/n-6 ratio.

The DHA levels in pre-spawning and spawning season ranged between 10.16 and 11.47% (i.e. 0.36 and 0.28 g DHA per 100 g fish muscle) with a whole year average value of 0.20 g DHA per 100 g fish muscle. Muscle DHA levels in pre-spawning and spawning seasons were significantly ($P < 0.05$) higher than those in other seasons and no significant ($P > 0.05$) differences were observed between the muscle DHA levels in post-spawning and summer seasons. The higher levels of muscle DHA in the muscle are in good agreement with the data from wild sea bream (Hossain *et al*., 2012), sea bass (Orban *et al*., 2003) and gilthead bream (Mnari *et al*., 2007), but these DHA values are lower than those reported for wild white sea bass (Cejas *et al*., 2004), red porgy (Rueda *et al*., 1997) and sea bass (Fuentes *et al*., 2010). In the present study, the average DHA values (7.85%) observed are higher than the reported values of 3.3% for gilthead bream (Orban *et al*., 2003) and 6.5% for blue fin sea bream (Hossain *et al*., 2012). The amount of muscle EPA and DHA in pre-spawning and spawning season is much higher than those in other seasons. The higher EPA and DHA in sobaity muscle during pre-spawning and spawning might be related to diverse feeding habits and fat accumulation in the preceding season and enhancement of gonadal development i.e. sexual changes in connection with spawning. Thus, the nutritional value of sobaity sea bream during these months of the year is higher (Mozaffarian *et al*., 2005; Mnari *et al*., 2007).

The n-3/n-6 ratio is an indication of the biomedical importance of fish (Chakraborty *et al*., 2017). Anthropological and nutritional studies indicate that a very low n-3/n-6 ratio in the diet may have adverse effects, while higher levels of n-3/n-6 ratios may be beneficial (Simopoulos, 2008). The total n-3 and n-6 FAs in muscle were significantly ($P < 0.05$) higher in pre-spawning and spawning seasons compared to those in other seasons indicating a better nutritional value of sobaity during these seasons of the year.

Table 4. Muscle FA profile (% of total FAs) of wild sobaity (male and female combined) in different seasons (values are mean ± SD, N = 3)

	Seasons[a]				
Fatty acids	Pre-spawning	Spawning	Post-spawning	Summer	One year average
C14:0	3.51bc ± 0.52	2.50c ± 0.62	5.24ab ± 1.16	7.39a ± 1.42	4.66 ± 2.12
C15:0	1.07a ± 0.32	0.94a ± 0.63	1.50a ± 0.21	1.50a ± 0.23	1.26 ± 0.45
C16:0	24.27b ± 1.94	23.31b ± 1.22	27.93a ± 0.44	28.17a ± 1.53	25.92 ± 2.25
C17:0	1.42a ± 0.16	1.16a ± 0.24	0.98a ± 0.23	1.11a ± 0.45	1.17 ± 0.30
C18:0	8.47a ± 0.21	8.37a ± 0.60	7.35ab ± 0.65	6.74b ± 0.74	7.70 ± 0.90
C20:0	ND	ND	ND	ND	ND
C21:0	0.43b ± 0.04	0.62ab ± 0.03	0.99a ± 0.33	0.69ab ± 0.20	0.68 ± 0.27
C22:0	0.39a ± 0.04	0.36a ± 0/04	0.49a ± 0.15	0.33a ± 0.05	0.39 ± 0.10
C16:1	8.29b ± 1.97	6.36b ± 1.14	12.32a ± 0.93	11.76a ± 0.99	9.69 ± 2.81
C17:1	1.23ab ± 0.42	0.58b ± 0.11	1.77a ± 0.41	1.76a ± 0.51	1.34 ± 0.61
C18:1n-9	16.31a ± 1.45	20.17a ± 4.67	21.82a ± 0.90	18.97a ± 1.79	19.32 ± 3.08
C20:1n-9	0.90a ± 0.47	0.46ab ± 0.21	0.39ab ± 0.14	0.19b ± 0.03	0.49 ± 0.14
C22:1n-9	1.77a ± 0.02	2.54a ± 1.45	2.45a ± 0.64	2.08a ± 0.22	2.21 ± 0.36
C24:1n-9	4.07a ± 0.59	2.27ab ± 2.20	0.69b ± 0.14	0.73b ± 0.13	1.94 ± 1.75
C18:2n-6	1.50a ± 0.28	2.06a ± 0.65	2.15a ± 0.11	1.95a ± 0.17	1.92 ± 0.41
C18:3n-3	1.07a ± 0.12	0.94a ± 0.15	1.26a ± 0.51	0.96a ± 0.21	1.06 ± 0.28
C18:3n-6	1.41 ± 0.91	0.56 ± 0.05	ND	ND	0.98 ± 0.74
C20:3n-3	0.56 ± 0.05	0.51 ± 0.05	ND	ND	0.54 ± 0.05
C20:3n-6	4.92a ± 0.76	3.76a ± 1.42	0.40b ± 0.14	0.42b ± 0.12	2.38 ± 2.21
C20:5n-3, EPA	4.95a ± 0.11 (0.17)[b]	2.80b ± 1.60 (0.07)	1.31b ± 0.22 (0.03)	1.11b ± 0.08 (0.02)	2.25 ± 1.75 (0.06)
C22:6n-3, DHA	10.16a ± 3.86 (0.36)	11.47a ± 3.39 (0.28)	5.19b ± 0.61 (0.10)	4.59b ± 0.18 (0.09)	7.85 ± 3.85 (0.19)
∑SFA	39.55ab ± 2.53	38.98b ± 2.71	44.80ab ± 1.05	46.12a ± 3.36	41.81 ± 3.94
∑MUFA	32.13b ± 3.39	32.38b ± 2.63	35.16ab ± 0.92	39.44a ± 1.17	36.42 ± 3.64
∑PUFA	23.94a ± 4.46 (0.84)	21.76a ± 5.61 (0.52)	10.30b ± 0.77 (0.21)	9.01b ± 0.09 (0.18)	17.29 ± 7.61 (0.42)
∑n-3	16.74a ± 3.87	15.72a ± 4.76	7.75b ± 0.79	6.64b ± 0.19	12.00 ± 5.44
∑n-6	7.17a ± 0.62	6.36a ± 0.82	2.55b ± 0.05	2.37b ± 0.26	5.29 ± 2.32
n-3/n-6 ratio	2.34a ± 0.40	2.45a ± 0.42	3.05a ± 0.32	2.82a ± 0.45	2.67 ± 0.46

[a]Pre-spawning = (October–December), spawning = (January–March), post-spawning = (April–June) and summer = (July–September).
[b]Figures within the parentheses indicate absolute values i.e. g of FA in 100 g of fish muscle.
ND, not detected; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; SFA, saturated fatty acid; MUFA, mono-saturated fatty acid; PUFA, polyunsaturated fatty acids.

Marine fish contain large amounts of n-3 PUFA particularly EPA and DHA. Despite this marine fish can neither biosynthesize EPA and DHA *de novo* nor from shorter chain precursors such as alpha lenoleic acid (ALA, C18:3n-3). Therefore, they have a dietary requirement for EPA and DHA (Sargent *et al.*, 1989). On the other hand, the natural diets of many freshwater fish are not rich in DHA, being rich instead in linoleic acid (LA, C18:2n-6) and ALA and to lesser extent, EPA. Thus, the conversion of LA to EPA to DHA is necessary. As these fish has access to diverse foods containing precursors of long chain PUFA, the conversion process may occur through δ−5 desaturase and δ−6 desaturase enzymes promoting elongation and desaturation (Tocher, 2003).

No significant ($P > 0.05$) differences were observed between the muscle n-3/n-6 ratios in different seasons, these ranging between 2.34 and 3.05. These n-3/n-6 ratios of wild sea bream are in agreement with other studies of wild sobaity bream (Hossain *et al.*, 2012), gilthead bream (Orban *et al.*, 2003), red porgy (Rueda *et al.*, 1997) and sea bass (Orban *et al.*, 2003). In general, higher ratios of n-3/n-6 found in wild fish compared with cultured fish indicate that the marine environment offers a better source of n-3 PUFAs for fish as they have access to a variety of food organisms containing high n-3 PUFAs (Grigorakis *et al.*, 2002; Fuentes *et al.*, 2010). The n-3/n-6 ratio differences may be because of the variability of the lipid levels in fish muscle, which depend on the species, season, age, size, reproduction period, as well as the FA composition of the eating regimen (Sirot *et al.*, 2008).

Season is an important factor that could considerably affect the biochemical composition of fish and consequently the nutritional value of the fish to consumers. In the present study, the period of gonadal maturation and spawning extending from October to March corresponded to fish muscle having higher n-3 PUFA, in particular, the DHA indicating a better nutritional value of sobaity sea bream. Similar better nutritional value in terms of n-3 PUFA during the pre-spawning season compared with other seasons was reported for golden grey mullet, *L. aurata* (Khitouni *et al.*, 2014).

The sobaity bream is a protandric hermaphrodite; the majority of individuals are first males, then become females. Abou-Seedo *et al.* (2003) reported that sobaity bream in Kuwait waters

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Table 5. Muscle EPA, DHA, SFA, MUFA, PUFA, ∑n-3, ∑n-6 and ∑n-3/∑n-6 ratios of male and female sobaity (% of total FAs) from October 2015 to September 2016[a]

Season[b]	Sex	EPA	DHA	SFA	MUFA	PUFA	∑n-3	∑n-6	∑n-3/∑n-6
Pre-spawning	Male	5.18a ± 0.78	10.85a ± 2.97	38.73b ± 2.60	31.28c ± 4.93	25.36a ± 4.52	17.57a ± 2.2	7.76a ± 1.36	2.26a ± 0.04
	Female	4.73a ± 0.65	9.47a ± 2.97	40.39b ± 2.58	33.06abc ± 2.50	22.53a ± 4.53	15.91a ± 2.58	6.62a ± 0.54	2.41a ± 0.78
Spawning	Male	2.78b ± 0.48	11.81a ± 2.09	38.22b ± 0.75	31.68bc ± 2.35	22.89a ± 5.63	16.27a ± 2.17	6.62a ± 0.46	2.43a ± 0.61
	Female	2.84b ± 0.73	11.13a ± 2.81	39.75b ± 2.69	33.09abc ± 3.31	21.30a ± 5.48	15.17a ± 2.45	6.13a ± 1.24	2.46a ± 0.41
Post-spawning	Male	1.31c ± 0.25	5.32b ± 0.67	44.49a ± 2.20	38.79ab ± 1.37	10.50b ± 0.71	7.94b ± 0.82	2.56b ± 0.16	3.11a ± 0.47
	Female	1.30c ± 0.21	5.06b ± 0.59	45.11a ± 0.64	40.10a ± 0.49	10.09b ± 0.85	7.56b ± 0.78	2.53b ± 0.23	2.99a ± 0.36
Summer	Male	1.05c ± 0.08	4.47b ± 0.20	44.23a ± 2.41	35.25abc ± 1.78	9.17b ± 0.34	6.64b ± 0.23	2.53b ± 0.37	2.69a ± 0.48
	Female	1.14c ± 0.10	4.70b ± 0.22	48.01a ± 4.32	35.28abc ± 0.81	8.85b ± 0.27	6.64b ± 0.23	2.20b ± 0.23	3.04a ± 0.36
Two-way ANOVA (*P*-value)									
Sex (A)		NS	NS	NS	NS	NS	NS	NS	NS
Season (B)		$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	NS
A × B		NS	NS	NS	NS	NS	NS	NS	Ns

[a]Values (mean ± SD, $n = 9$) in a column with same letters are significantly different as determined by Tukey's test ($P < 0.05$).
[b]Pre-spawning = (October–December), spawning = (January–March), post-spawning = (April–June) and summer = (July–September).

spawn from January to April with a February peak in males and a March peak in females and transitional fish. Abu-Hakima (1984) also observed that spawning in this species in Kuwait waters begins in January but in contrast, this author observed the end of spawning in March in the wild. For the enhancement of gametogenesis leading to maturity and spawning, the role of temperature has been well recognized. A strong negative correlation observed between the annual variations in GSI and sea temperature confirms that temperature, either alone or in combination with other factors, triggers spawning in *Acanthopagrus latus* (Abou-Seedo *et al.*, 2003). The spawning temperature for sobaity ranges between 19 and 23°C (Teng *et al.*, 1999). In relation to age, spawning generally starts at 20 months and peaks at 21 months in the males, while females and transitional fish start to spawn a month later at 21 months, with a peak at 22 months (Abou-Seedo *et al.*, 2003).

Seasonal variation influences the diet of fish. Petenuci *et al.* (2016) observed that the lipid contents of five fish species studied from the Amazon basin were lower in flood periods than in drought periods. These variations were attributed to different causes such as food availability and reproduction. As mentioned earlier, during the summer season the sobaity has an opportunity for intense feeding in particular on the abundant juvenile mullets in the Arabian Gulf enhancing the fat reserves for the pre-spawning and spawning seasons. Seasonality affects life cycles of fish, such as reproduction, body conditions, food intake and their immune response. These may ultimately influence the total lipid and FA composition, since those substances are used as energy sources and are precursors for the production of biochemicals in fish such as eicasonoids and prostaglandins (Tocher, 2003). A review of seafood from the Indo-Pacific region found that with increased latitude there was a concomitant increase in n-3 PUFA with DHA being particularly high in fish from cooler waters (Dunstan *et al.*, 1999). However, there are some exceptions, with some tuna species caught in warm water showing particularly high absolute values of DHA and therefore of total n-3 PUFA (Visentiner *et al.*, 2007). In sea bass (*Dicentrarchus labrax*), Cordier *et al.* (2002) found a significant correlation between water salinity and percentage of DHA in muscle, liver and gill phospholipids, but no correlation was found between per cent DHA and water temperature.

Table 5 shows the seasonal variations in muscle EPA, DHA, SFA, MUFA, PUFA, ∑n-3, ∑n-6 content and ∑n-3/∑n-6 ratios of male and female sobaity. No interactive effects ($P > 0.05$) of sex and season were observed, but the season alone had a significant effect on EPA, DHA, SFA, MUFA, PUFA, ∑n-3 and ∑n-6 FA contents of sobaity. Both male and female sobaity muscle had significantly higher DHA during the pre-spawning and spawning seasons. Hossain *et al.* (2010) also reported similar higher muscle DHA levels in both male and female silver pomfret (*P. argenteus*) during pre-spawning and spawning season. Muscles of both male and female sobaity bream in the present study demonstrated a higher level of saturation of FAs at the commencement of the post-spawning and summer seasons. Romotowska *et al.* (2016) also observed a higher degree of saturation of FAs in Atlantic mackerel at the start of summer. On the other hand, the level of unsaturation i.e. the PUFA profile in muscles of both male and female sobaity bream were higher during the pre-spawning and spawning seasons. The level of unsaturation of FAs in fish might be linked to the seasonal variations in lipid content of fish owing to the environmental conditions, such as water temperature, food availability and food composition (Celik, 2008).

The high percentage of ∑PUFA in male (15.51–16.14%) and female (14.40–15.51%) gonads during pre-spawning and spawning seasons was compensated by lower levels of ∑PUFA in the livers of male (7.98–11.15%) and female (7.46–9.06%) sobaity (results not shown in tables). Henderson *et al.* (1984) postulated that the intervention of the liver in the transformation of FAs from muscle triglycerides into egg phospholipids could easily account for the compositional change in the muscle and ovarian lipid of capelin (*Mollottus villosus*). It is well known that the liver is the site of biosynthesis of specific lipoproteins for gonads (Plack *et al*., 1971). Alamansa *et al*. (2001) showed that broodstock gilthead sea bream females drew upon their lipid reserves from liver and muscle during ovary maturation, and these lipids contributed to form the lipid reserves of the eggs and serve as an energetic and structural substrate for the specific lipoprotein synthesis, which transports lipids and proteins from the liver to ovaries. Decrease in liver and muscle at the onset of spawning season have been described in several species such as capelin (Henderson *et al*., 1984), Atlantic cod (Love & Black, 1990) and salmonids (Green & Selivonchick, 1987).

Conclusion

The results of the present investigation showed that seasonal variability affected the proximate composition and FA profile of sobaity. These results also demonstrated that sobaity is a promising source of essential FAs. For a direct comparison of the lipid quality of fish from different sources, an estimation of the absolute amount of total n-3 and n-6 PUFAs in fish muscle is important from the point of view of human consumption. Based on the whole year average of PUFA content (17.29%, i.e. 0.42 g PUFA in 100 g fish muscle), sobaity bream can be considered as a nutritionally healthy fish. However, it can be said that sobaity caught during pre-spawning and spawning seasons (October–March) are nutritionally better than those in other seasons because of higher levels (21.76–23.94%, i.e. 0.52–0.84 g PUFA in 100 g fish muscle) of PUFAs, in particular higher levels of DHA. A typical western diet is characterized by a high intake of n-6 PUFA and low intake of n-3 PUFA. According to nutritional advisers, it would be beneficial to increase the levels of n-3 PUFA in diets so as to increase the n-3/n-6 ratio. Consumption of fish with the hope of increasing the n-3 PUFA concentration may not be effective as this may cause an associated increase in the n-6 concentration as well. However, the good n-3/n-6 ratio of 2.26–3.11 observed in sobaity throughout the year could be considered as a positive attribute from a nutritional standpoint.

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References

Abou-Seedo FS, Dadzie S and Al-Kannan KA (2003) Sexuality, sex change and maturation patterns in the yellowfin seabream, *Acanthopagrus latus* (Teleotei: Sparidae (Houttuyn, 1782)). *Journal of Applied Ichthyology* **19**, 65–73.

Abu-Hakima R (1984) Some aspects of the reproductive biology *of Acanthopagrus* spp. (Family Sparidae). *Journal of Fish Biology* **25**, 515–526.

Ackman RG (1989) Nutritional composition of fats in sea foods. *Progress in Food and Nutrition Science* **13**, 161–241.

Alamansa E, Martin MV, Cejas JR, Badia P, Jeres S and Lorenzo A (2001) Lipid and fatty acid composition of female gilthead sea bream during their reproductive cycle: effect of a diet lacking n-3 HUFA. *Journal of Fish Biology* **59**, 267–286.

Alasalvar C, Taylor KDA, Jubcob E, Shahidi F and Alexis M (2002) Differentiation of cultured and wild sea bass (*Dicentrarchus labrax*): total lipid content, fatty acid, and trace mineral composition. *Food Chemistry* **79**, 145–150.

Alhassan EH, Abobo SM, Mensah S and Boti F (2014) The spawning pattern, length-weight relationship and condition factor of elephant fish, *Mormyrus rume* from the Bontanga reservoir, Ghana. *International Journal of Fisheries and Aquatic Studies* **2**, 109–114.

Almatar SM, Lone KP, Abu-Rezq TS and Yousef AA (2004) Spawning frequency, fecundity, egg weight and spawning type of silver pomfret, *Pampus argenteus* (Euphrasen) in Kuwait waters. *Journal of Applied Ichthyology* **20**, 176–188.

AOAC (2000) *Official Methods of Analysis*, 17th Edn. Washington, DC: Association of Official Analytical Chemists.

AOCS (1992) *Fatty Acid Composition by GLC. Marine Oils*. AOCS Official Methods Ce 1b-89, Champaign, IL: American Oil Chemists' Society.

Bligh EC and Dyer WJ (1959) A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology* **37**, 911–917.

Cejas JR, Almansa E, Jerez S, Bollanos A, Samper M and Lorenzo A (2004) Lipid and fatty acid composition of muscle and liver from wild and captive mature female brood stock of white sea bream, *Diplodus sargus*. *Comparative Biochemistry and Physiology Part B* **138**, 91–102.

Celik M (2008) Seasonal changes in the proximate chemical compositions and fatty acids of chub mackerel (*Scomber japonicus*) and horse mackerel (*Trachurus trachurus*) from the North Eastern Mediterranean Sea. *International Journal of Food Science and Technology* **43**, 933–938.

Chakraborty K, Rola VK, Joy M and Makkar F (2017) Nutritional attributes in the fillet of skipjack tuna (*Katsuwonus pelamis*) from the Arabian Sea near the south-west cost of India. *Journal of the Marine Biological Association of the United Kingdom* **97**, 419–432.

Cordier M, Brichon D, Weber JM and Zwingelstein G (2002) Changes in the fatty acid composition of phospholipids in tissues of farmed sea bass (*Dicentrarchus labrax*) during an annual cycle. Roles of environmental temperature and salinity. *Comparative Biochemistry and Physiology Part B* **133**, 281–288.

Delgado-Lista J, Perez-Martenez P, Lopez-Miranda J and Perez-Jimenz F (2012) Long chain omega-3 fatty acids and cardiovascular disease: a systematic review. *British Journal of Nutrition* **107**, S201–S213.

Duncan DB (1955) Multiple range and multiple F-test. *Biometrics* **11**, 1–42.

Dunstan GA, Olley J and Ratkowsky DA (1999) Major environmental and biological factors influencing the fatty acid composition of seafood from Indo-Pacific to Antarctic waters. *Recent Research Developments in Lipid Research* **3**, 63–86.

Fuentes A, Fernandez-Segovia I, Serra JA and Barat JM (2010) Comparison of wild and cultured sea bass (*Dicentrarchus labrax*) quality. *Food Chemistry* **119**, 1514–1518.

Green D and Selivonchick P (1987) Lipid metabolism in fish. *Progressive Lipid Research* **26**, 53–85.

Grigorakis K (2007) Composition and organoleptic quality of farmed and wild gilthead sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) and factors affecting it: a review. *Aquaculture* **272**, 55–75.

Grigorakis K, Taylor KDA and Alexis MN (2002) Comparison of wild and cultured gilthead sea bream; composition, appearance and seasonal alterations. *International Journal of Food Science and Technology* **37**, 477–484.

Hartman L and Logo RC (1973) Rapid preparation of fatty acid methyl esters from lipids. *Laboratory Practices* **22**, 475–476.

Henderson RJ, Sargent JR and Hopkins CCF (1984) Changes in the content and fatty acid composition of lipid in an isolated population of capelin *Mollotus villosus* during sexual maturation and spawning. *Marine Biology* **78**, 225–263.

Hossain MA, Almatar SM, James CM, Al-Yakout A and Yaseen SB (2010) Seasonal variations in fatty acid composition of silver pomfrets, *Pampus argenteus* (Euphasen) in Kuwait waters. *Journal of Applied Ichthyology* **27**, 901–907.

Hossain MA, Almatar SM, Al-Abdul-Elah KM and Yaseen SB (2012) Comparison of proximate and fatty acid profiles in cultured and wild marine fishes in Kuwait. *Journal of Applied Aquaculture* **24**, 199–209.

Hossain MA, Al-Abdul-Elah KM and El-Dakour S (2017) Evaluation of different commercial feeds on grow-out blue finned sea bream, *Sparidentex hasta* (Valencinnes) for optimum growth performance, fillet quality, and cost of production. *Saudi Journal of Biological Sciences* **24**, 71–79.

Khitouni IK, Mihoubi NB, Bouain A and Rebah FB (2014) Seasonal variations in proximate and fatty acid composition of golden grey mullet *Liza* *aurata* from the Tunisian coast. *International Journal of Agricultural Policy and Research* **2**, 273–280.

Kitto MR (2004) Sobaity – the Arab's choice. *Fish Farmer Magazine* Nov/Dec, 24–25.

Kris-Etherton PM, Harris WS and Appel LJ (2002) Fish consumption, fish oil, omega-3 fatty acid and cardiovascular disease. *Circulation* **106**, 2747–2757.

Leaver MJ, Bautista JM, Bjornsson BT, Krey G, Tocher DR and Torstensen BE (2008) Towards fish lipid nutrigenomics: current state and prospects for fin-fish aquaculture. *Reviews in Fisheries Science* **16**(S1), 73–94.

Love MR and Black D (1990) Dynamics of stored energy in North sea cod (*G. morhua* L) and cultured rainbow trout (*S. gairdneri* Richardson). In Mellinger J (ed.), *Animal Nutrition and Transport Process, 1. Nutrition in Wild and Domestic Animals*, Vol. **5**. Basel: Karger, pp. 193–202.

Martin NB, Houlihan DF, Talbot C and Palmer RM (1993) Protein-metabolism during sexual maturation in female Atlantic salmon (*Salmo salar* L.). *Fish Physiology and Biochemistry* **12**, 131–141.

Mnari A, Bouhlei I, Charaief I, Hammami M, Romdhane MS, El Casfi M and Chaouch A (2007) Fatty acids in muscles and liver of Tunisian wild and farmed gilthead seabream, *Sparus aurata*. *Food Chemistry* **100**, 1393–1397.

Mozaffarian D, Bryson CL, Lemaitre RN, Burke GL and Siscovick DS (2005) Fish intake and risk of incident heart failure. *Journal of the American College of Cardiology* **45**, 2015–2021.

Orban E, Nevigato T, Di Lena G, Casini I and Marzetti A (2003) Differentiation in the lipid quality of wild and farmed sea bass (*Dicentrarchus labrax*) and gilthead seabream. *Food Science* **68**, 128–132.

Orban E, Nevigato T, Masci M, Di Lena G, Casini I, Caproni R, Gambelli L, de Angelli P and Rampaci M (2007) Nutritional quality and safety of European perch (*Perca fluviatilis*) from three lakes of central Italy. *Food Chemistry* **100**, 482–490.

Orban E, Di Lena G, Nevigato T, Masci M, Casini I and Caproni R (2011) Proximate, unsaponifiable lipid and fatty acid composition of bogue (*Boops boops*) and horse mackerel (*Trachurus trachus*) from the Italian trawl fishery. *Journal of Food Composition Analysis* **24**, 1110–1116.

Petenuci ME, Rocha INA, de Souza SC, Schneider VVA, da Costa LAMA and Visentainer JV (2016) Seasonal variations in lipid content, fatty acid composition and nutritional profiles of five freshwater fish from the Amazon basin. *Journal of the American Oil Chemists Society* **93**, 1373–1381.

Plack PA, Pritchard DJ and Fraser NW (1971) Egg protein in cod serum. Natural occurrence and induction by injections of oestradiol 3-benzoate. *Biochemical Journal* **121**, 847–856.

Romotowska PE, Karlsdottir MG, Gudjonsdottir M, Kristinsson HG and Arason S (2016) Seasonal and geographical variation in chemical composition and lipid stability of Atlantic mackerel (*Scomber scombrus*) caught in Icelandic waters. *Journal of Food Composition Analysis* **49**, 9–18.

Rueda FM, Lopez JA, Martinez FJ, Zamora S, Divanch P and Kentouri M (1997) Fatty acids muscles of wild and farmed red porgy, *Pagrus pagrus*. *Aquaculture Nutrition* **3**, 161–165.

Sargent J, Henderson RJ and Tocher DR (1989) The lipids. In Halver J (ed.), *Fish Nutrition*. New York, NY: Academic Press, pp. 153–218.

Simopoulos AP (2008) The importance of omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. *Experimental Biology and Medicine* **233**, 674–688.

Sirot V, Oseredczuk M, Bemrah-Aouachria N, Volatier JL and Lablanc JC (2008) Lipid and fatty acid composition of fish and sea food consumed in France: CALIPSO study. *Journal of Food Composition Analysis* **21**, 8–16.

Shearer KD (1994) Factors affecting the proximate composition of cultured fishes with emphasis on salmonids. *Aquaculture* **119**, 63–88.

Teng SK, El-Zahr C, Al-Abdul-Elah K and Almatar S (1999) Pilot-scale spawning and fry production of blue-fin porgy, *Sparidentex hasta* (Valenciennes), in Kuwait. *Aquaculture* **178**, 27–41.

Teng SK, James CM, Al-Ahmad T, Rasheed V and Shehadeh Z (1987) Development of technology for commercial culture of sobaity fish in Kuwait. Vol. III. Recommended technology for commercial application. Kuwait Institute for Scientific Research. Report No. KISR 2269, Kuwait.

Tocher DR (2003) Metabolism and functions of lipids and fatty acids in Teleost fish. *Reviews in Fisheries Science* **11**, 107–184.

Tzikas Z, Amrosiadis I, Soultos N and Georgakis SP (2007) Seasonal variations in the chemical and microbiological condition of Mediterranean horse mackerel (*Trachurus mediterraneus*) muscle from the North Aegean Sea. *Food Control* **18**, 251–257.

Visentiner JV, Noffs MD, Carvalho PDO, de Almeida VV, de Oleveira CC and de Souza NF (2007) Lipid content and fatty acid composition of 15 marine fish species from the south coast of Brazil. *Journal of the American Oil Chemists Society* **84**, 543–547.

Yamada K, Kobayashi K and Yone A (1980) Conversion of linolenic acid to ω−3-highly unsaturated fatty acids in marine fishes and rainbow trout. *Bulletin of the Japanese Society of Scientific Fisheries* **46**, 1231–1233.